



DARK ENERGY
SURVEY

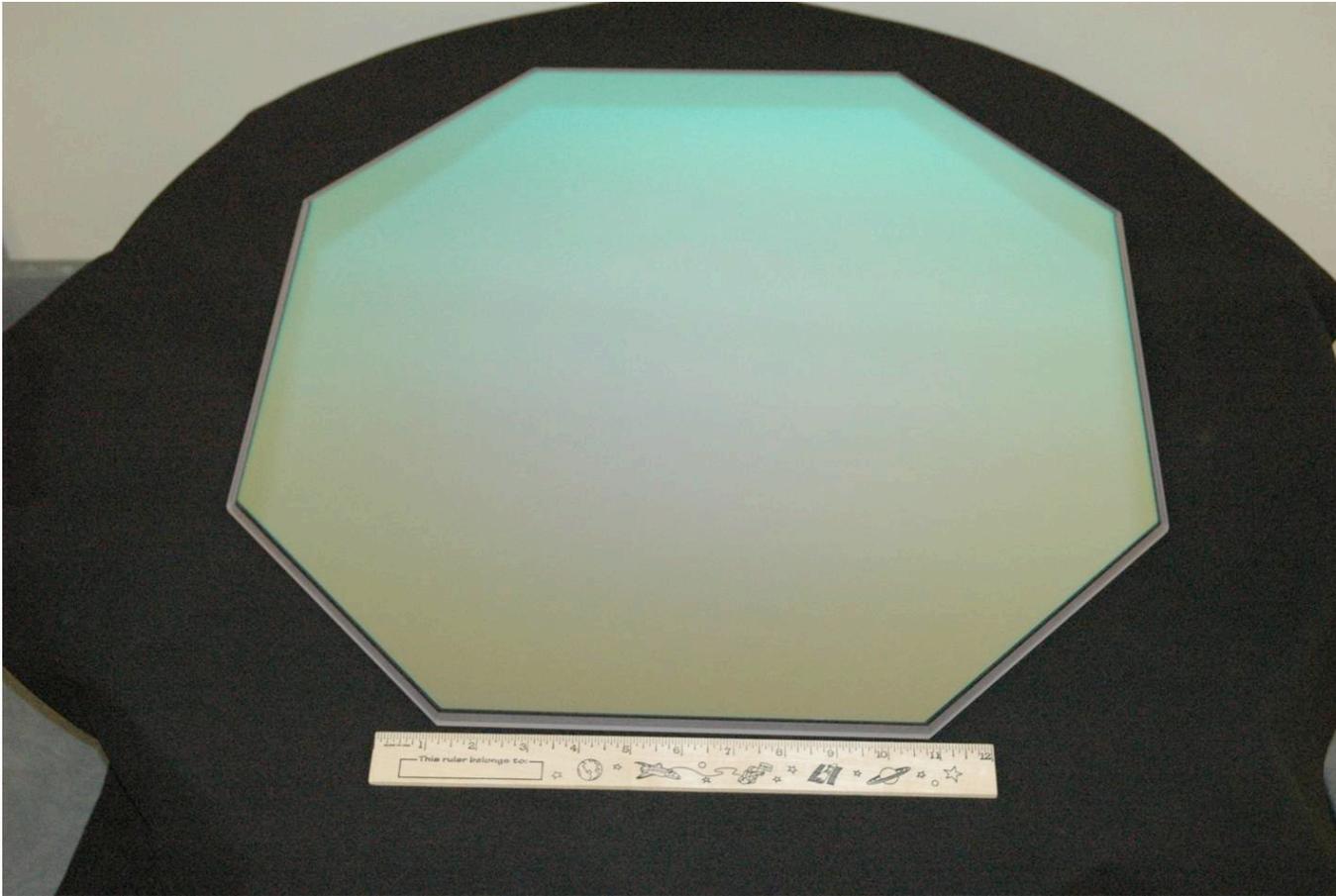
Analysis of Filter Transmission Uniformity Specifications

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Fermilab



DARK ENERGY
SURVEY

PanSTARRS Filters from Barr



• *Similar to DES filters:*

• *570 mm size*

• *10 mm thick*

• *Fused silica substrates*

• *Data on griz filters available*

*PanSTARRS
i-band filter*

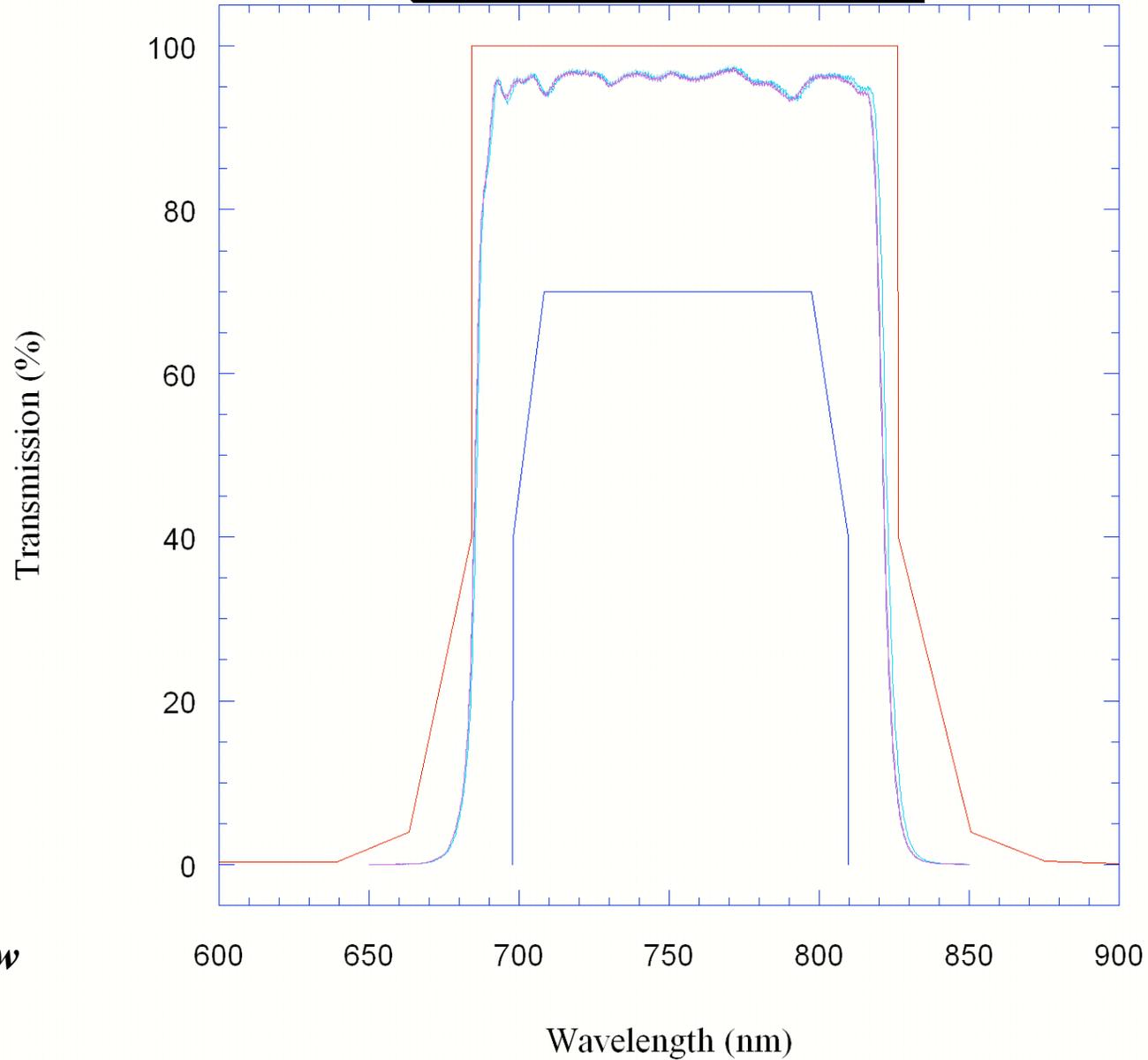
from B. Bigelow



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i band

i Band Transmission vs Azimuth



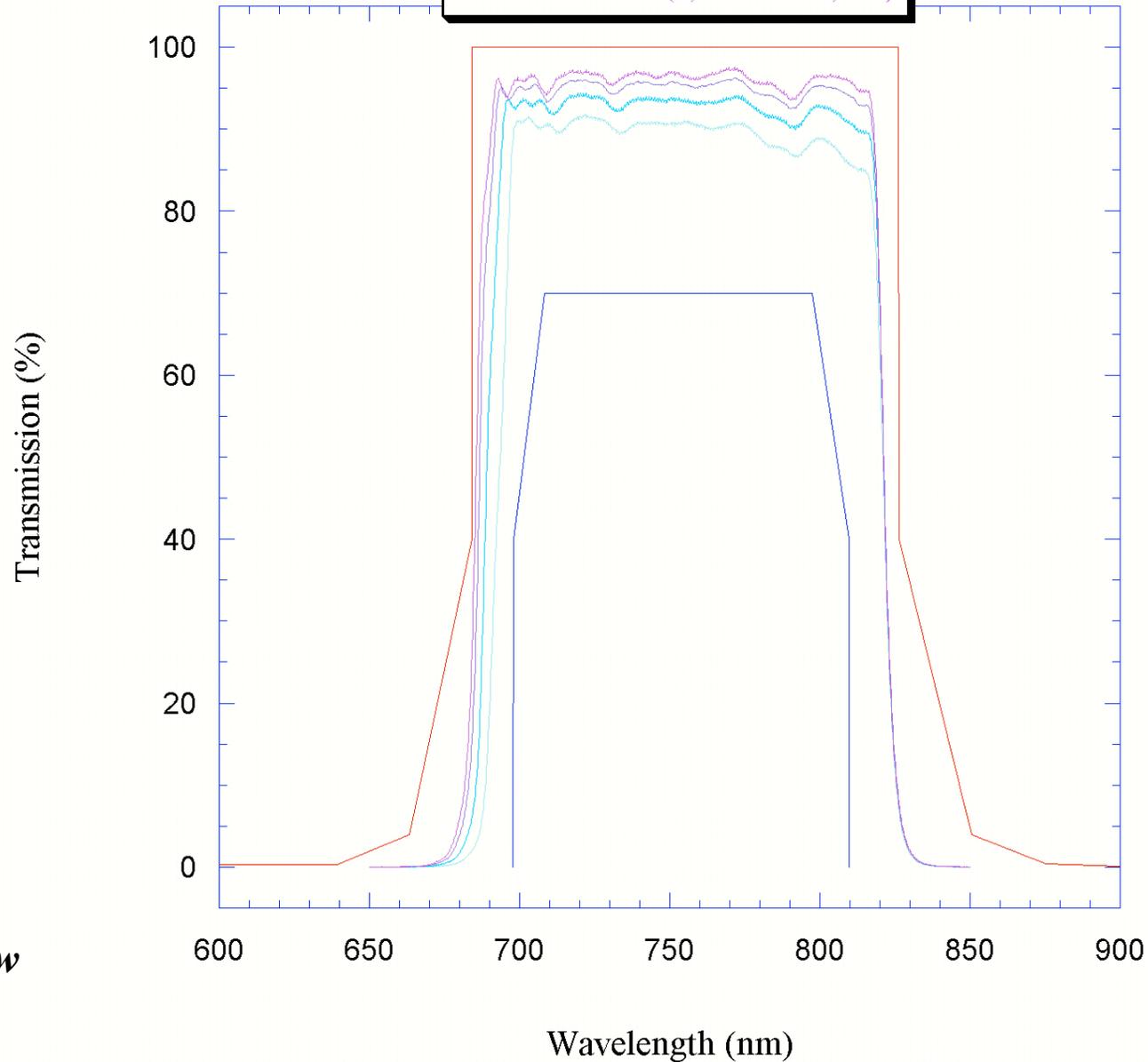
from B. Bigelow



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i band

i Band Transmission vs Radius from Filter Center



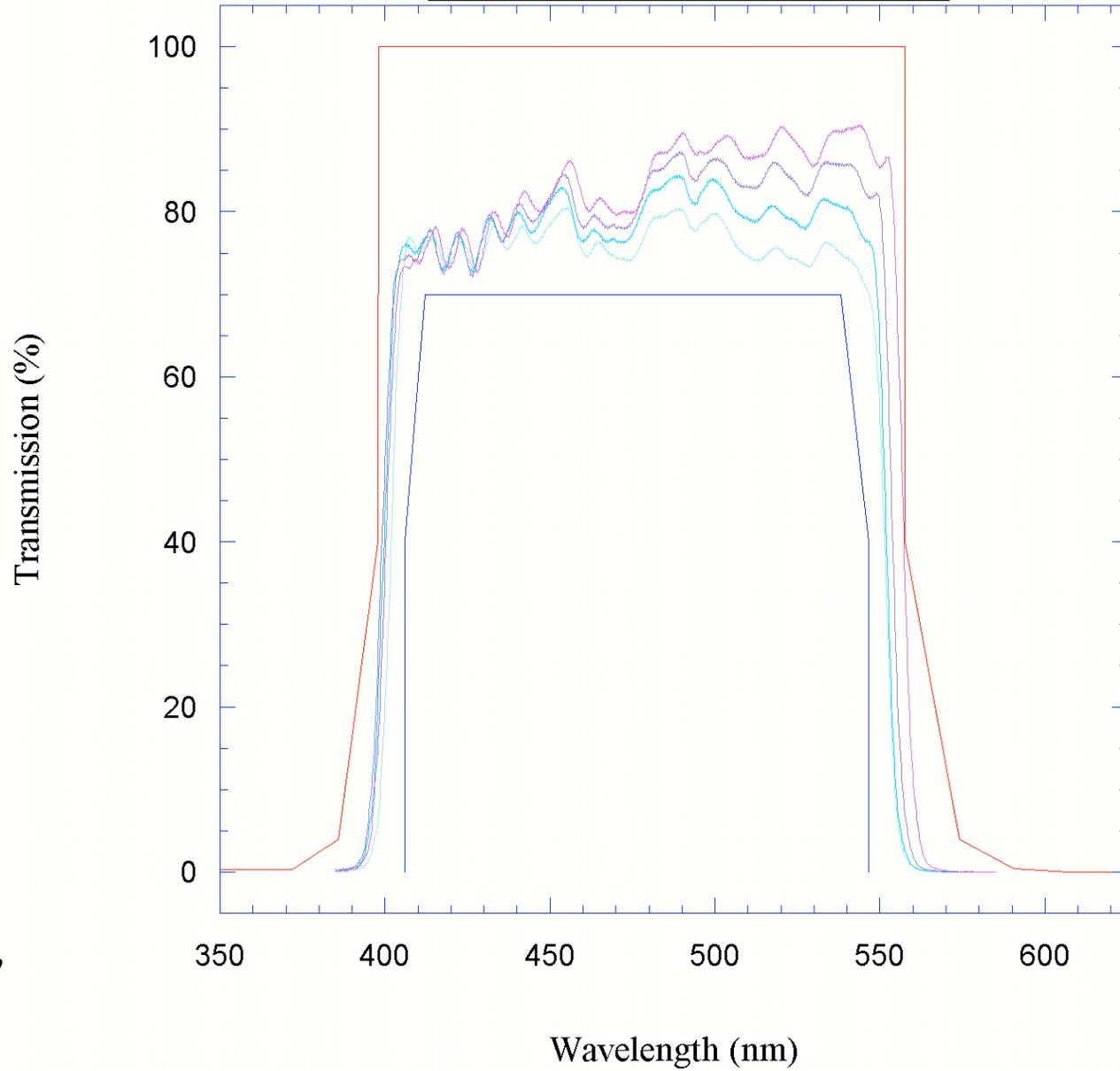
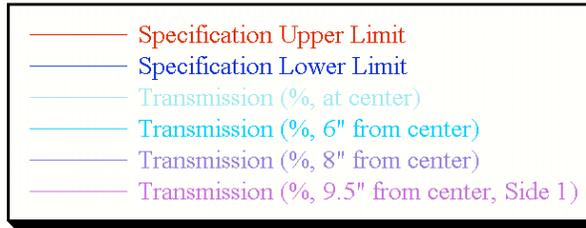
from B. Bigelow



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g band

g Band Transmission vs Radius from Filter Center



from B. Bigelow



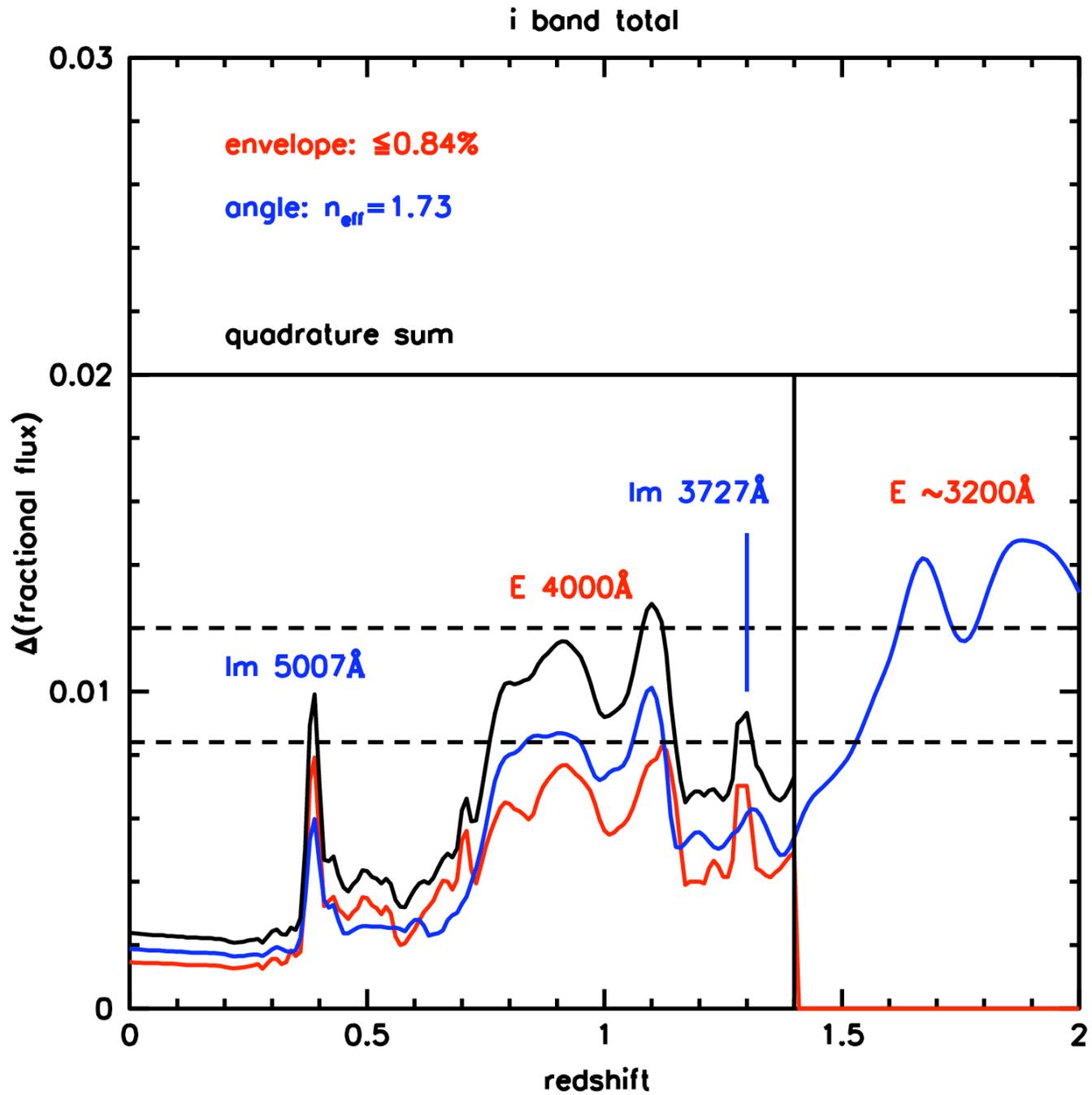
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Filter Transmission Uniformity Analysis

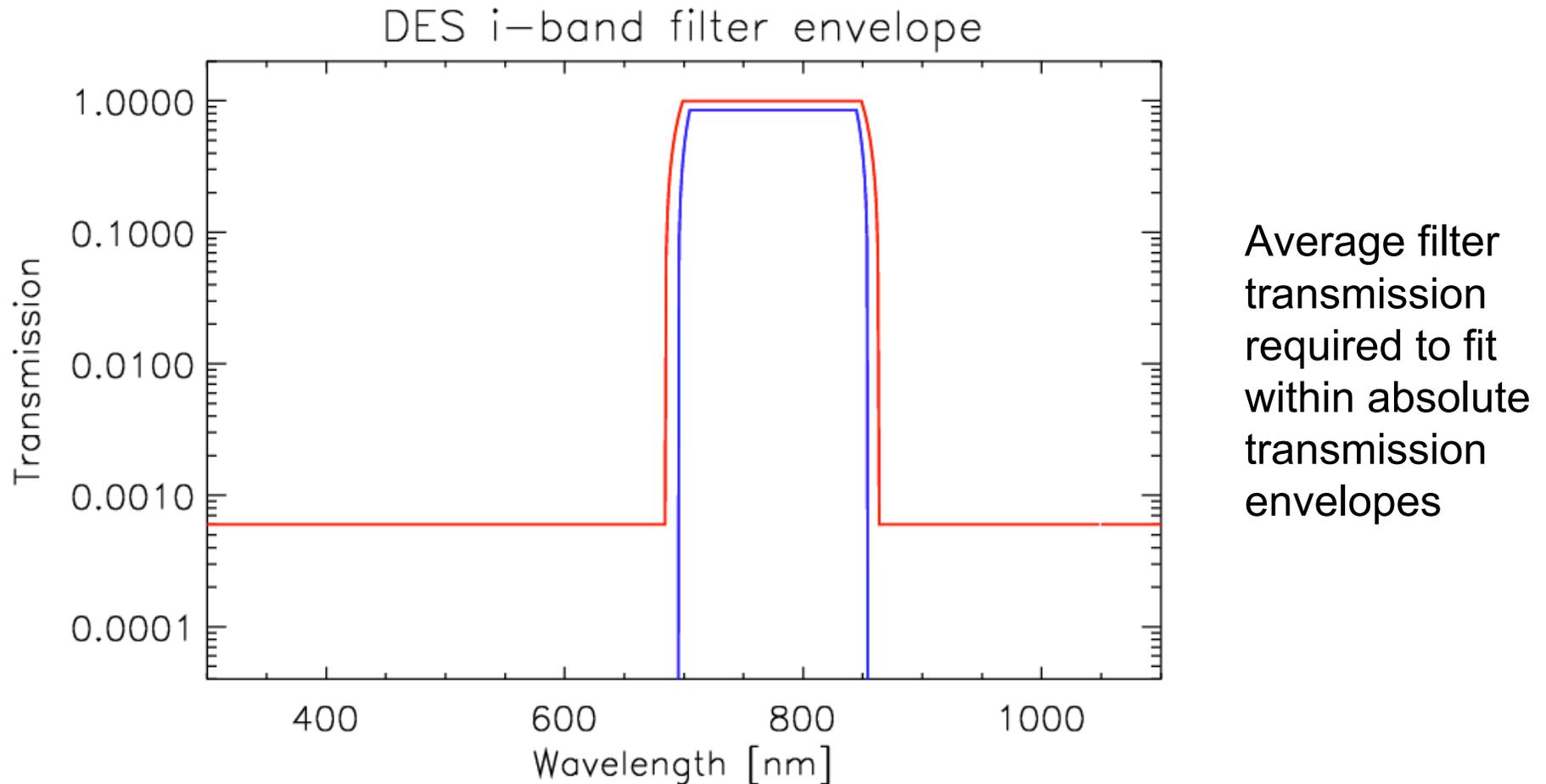
- **Give filter specifications to vendors using upper and lower absolute transmission envelopes, similar to PanSTARRS filters**
- **DES photometric calibration requirement is 2%; assign 1% error budget component to filters to account for spatial non-uniformity in filter transmissions**
- **Test sets of filter curves fitting within absolute envelopes in order to specify transmission spatial uniformity requirements**
- **Use galaxy SEDs (E, Sbc, Scd, Im) from Bruzual & Charlot GISSEL package: CWW SEDs extended using theoretical models to the UV and IR**
- **Calculate fractional flux differences, vs. *average* of all test filter curves, for 4 galaxy SEDs over redshift ranges relevant to main optical spectral features: 4000Å break, [OII] 3727 and [OIII] 5007 lines**
- **Also account for transmission variations due to changes in incidence angle over focal plane**
- **Use galaxy analysis results to define “fraction envelopes” on transmission uniformity**



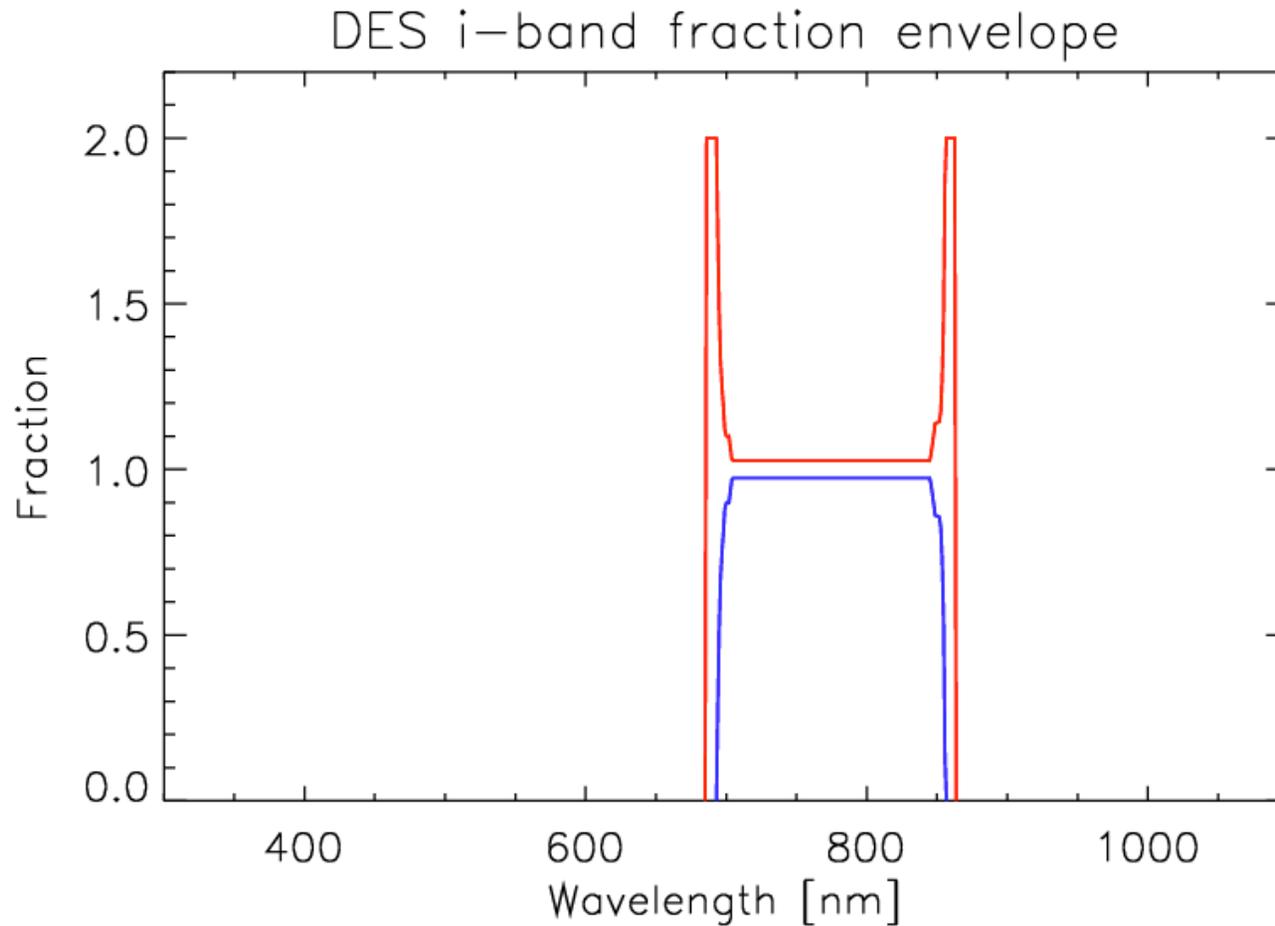
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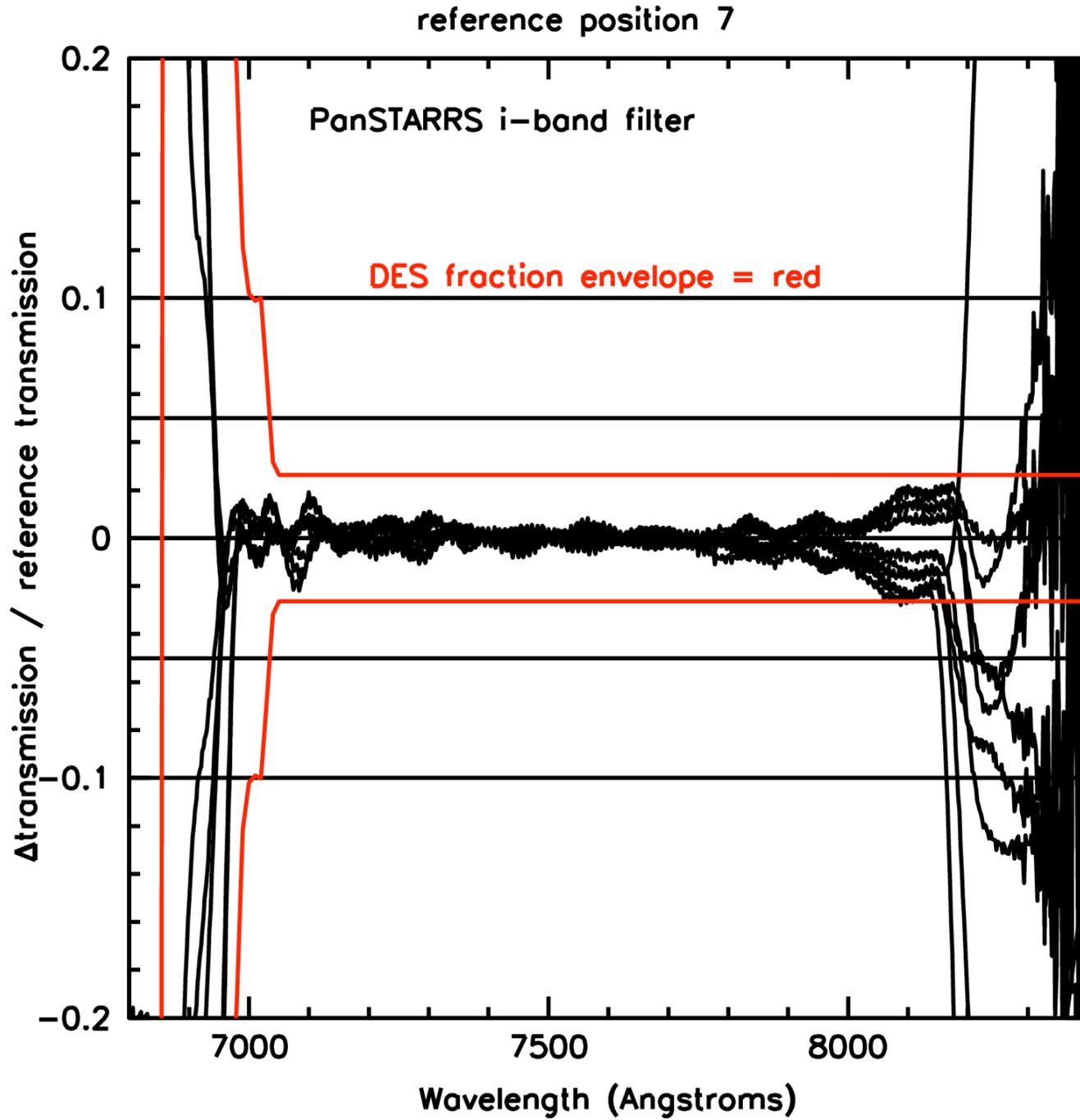
Example Absolute Transmission Envelopes for i-band Filter



Example Transmission Uniformity (“Fraction”) Envelopes for i-band Filter

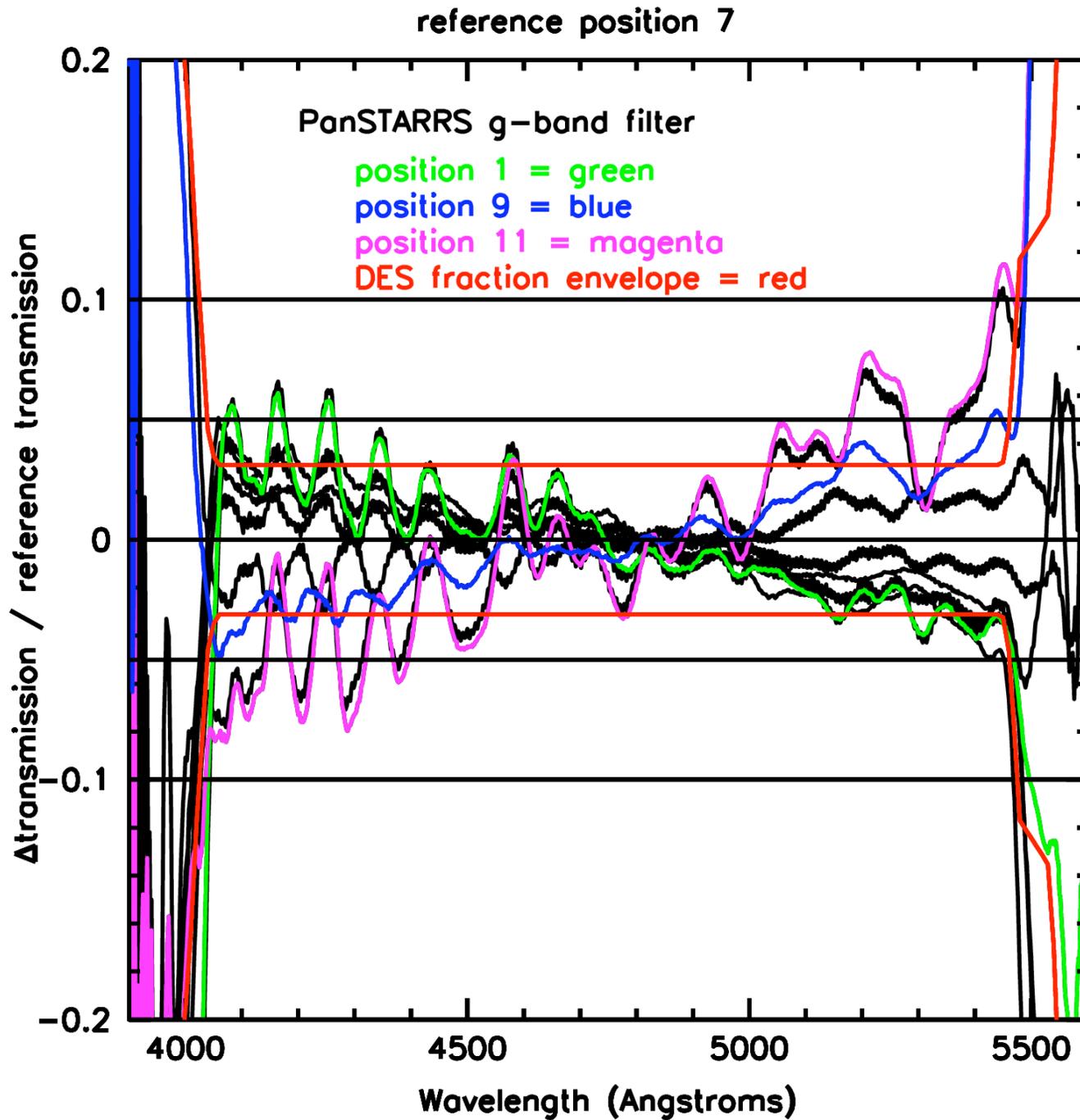


Shape of filter
transmission
relative to
average required
to fit within
“fraction”
envelopes





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Status

- **Derived filter transmission and spatial uniformity envelopes, based on relative photometric calibration requirements applied to galaxy spectra**
- **Contributions of “envelope” and “incidence angle” effects are about the same, for adopted 0.84% fractional flux cut used to define acceptable envelopes, and for Barr/PanSTARRS n_{eff} values**
- **Current acceptable envelopes should lead to < 1.2% fractional flux difference for galaxies**
- **Vendor responses to filter RFI (see M. Schubnell talk, docdb #1635) indicate it is too expensive and/or difficult to meet our current uniformity specifications, basically about 3% transmission variation over flat parts of filters**
- **Will try using color terms (which are no longer avoidable) and see if non-uniformity of Barr’s PanSTARRS filters can still be acceptable for DES**
- **Derive approximate relaxed uniformity specifications**



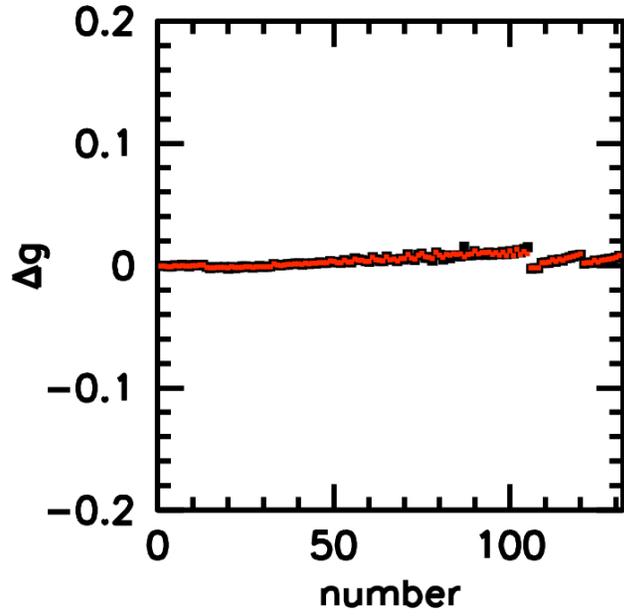
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Revised Filter Transmission Uniformity Analysis, with Color Terms

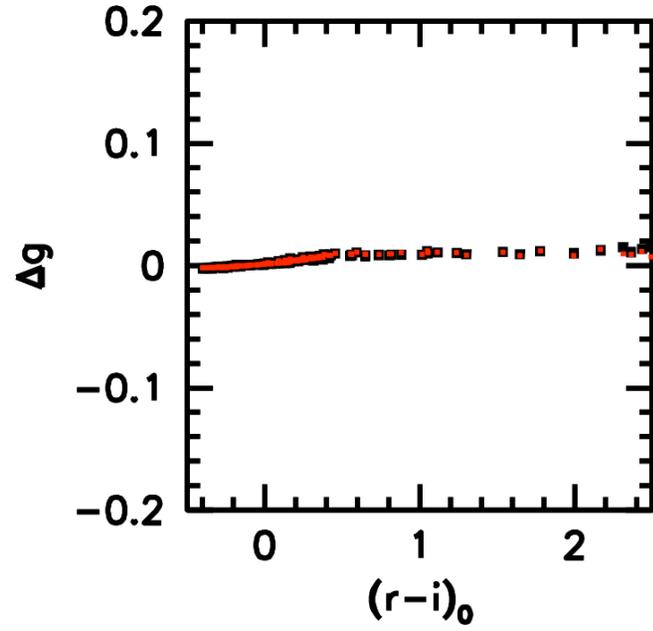
- **Use measured filter transmissions at different radial positions for PanSTARRS filters**
 - **Use position 7 as reference transmission; it's approximately the median (see next slide)**
- **Also use DES filters with gradients applied to derive results more directly applicable to DES, as PanSTARRS filter bandpasses differ in detail**
- **Use Pickles stellar library, with 131 spectra of wide range of stellar types, to derive transformations between the magnitudes at different filter positions**
- **Use quadratic fits: e.g., $g - g_0 = a + b(g_0 - r_0) + c(g_0 - r_0)^2$**
 - **Use reference colors $g-r$ for g , $r-i$ for r , and $i-z$ for i and z**
- **Use same galaxy SEDs (E, Sbc, Scd, Im) as before**
- **Also consider SN Ia “Hsiao” templates (via John Marriner) at -7, 0, +7, +14 days vs. maximum**
- **Apply color transformations from stars to galaxies and SNe and look at residuals vs. redshift and color**
- **Aim for 1% photometric errors as acceptable for the filter contribution to the total 2% error budget**



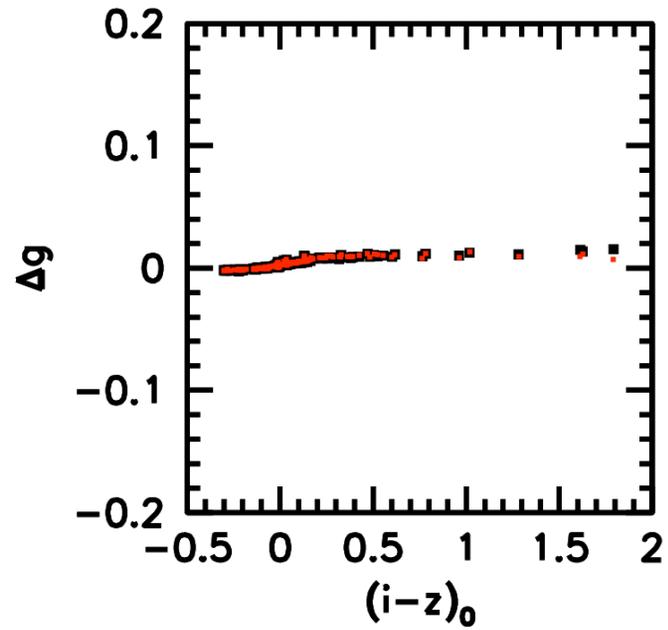
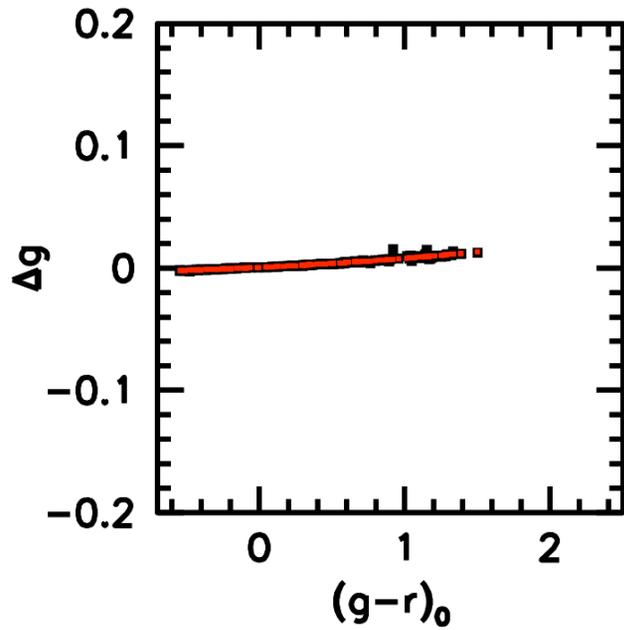
position 1 - position 7



Pickles stars quadratic fit

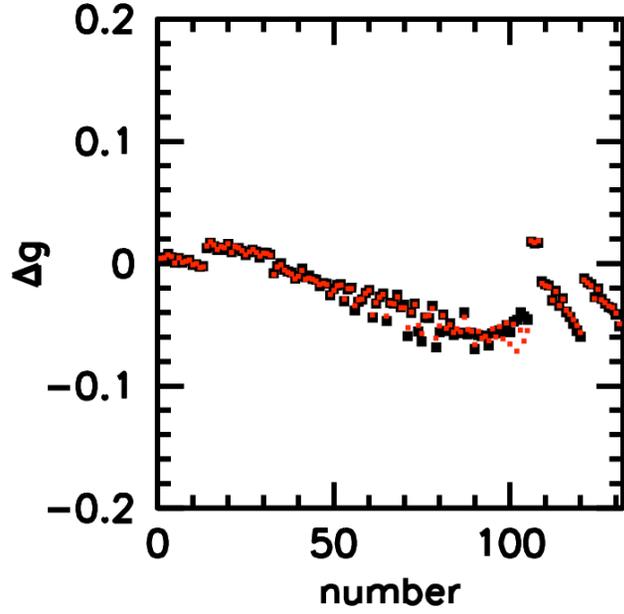


Stars

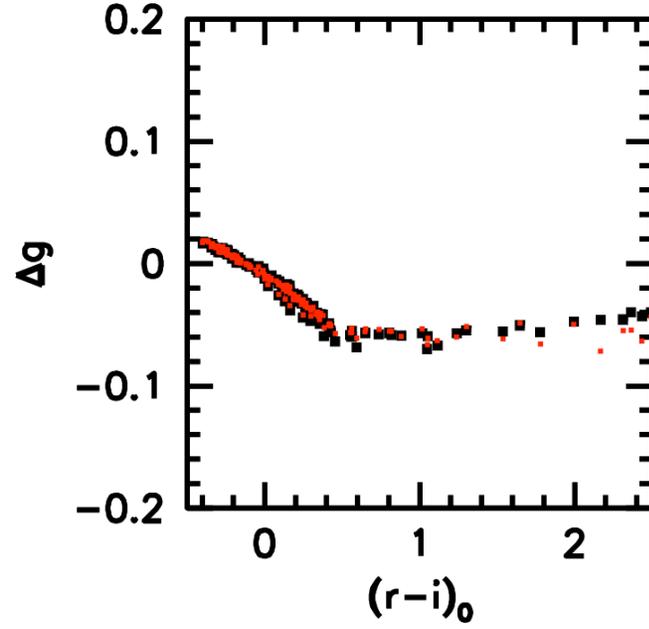




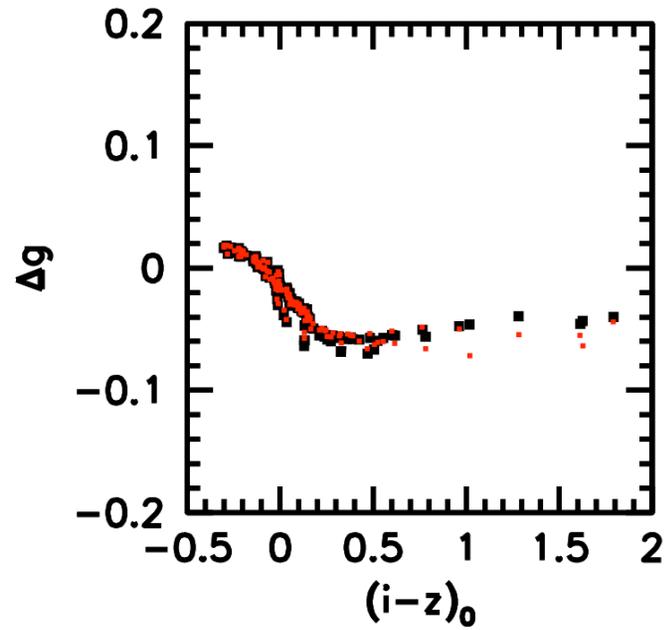
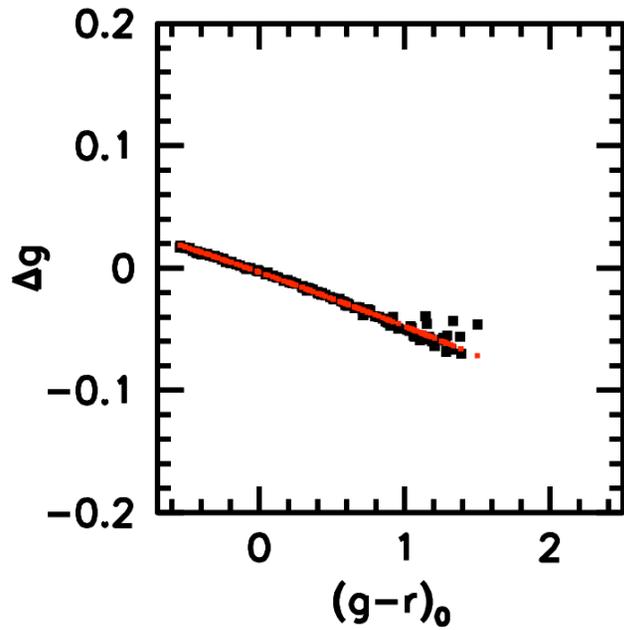
position 11 - position 7



Pickles stars quadratic fit

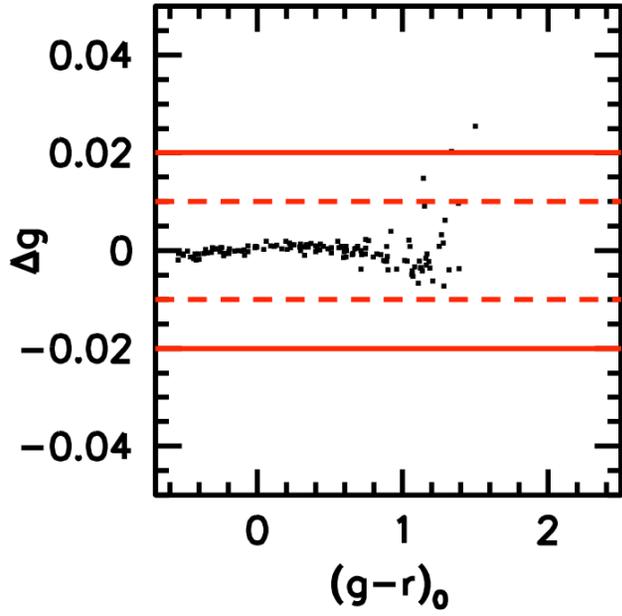


Stars

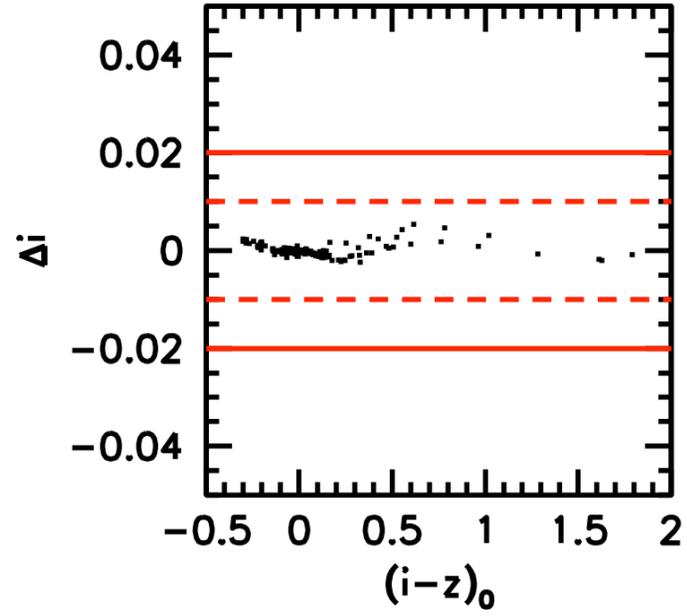




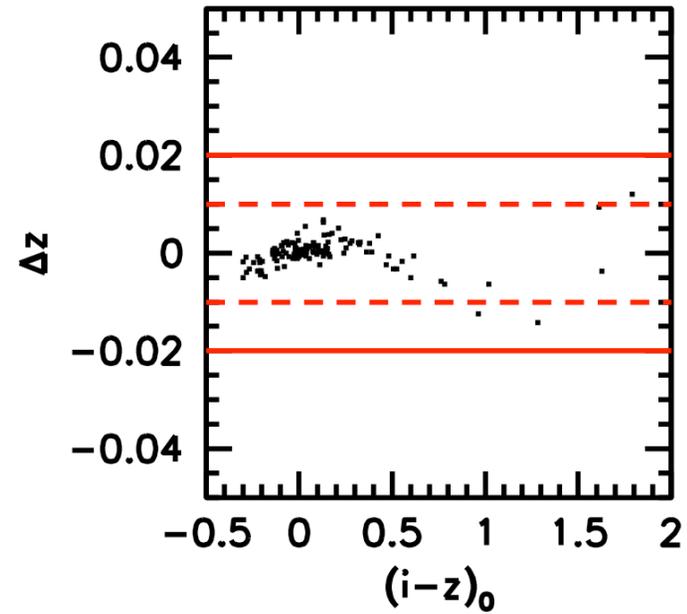
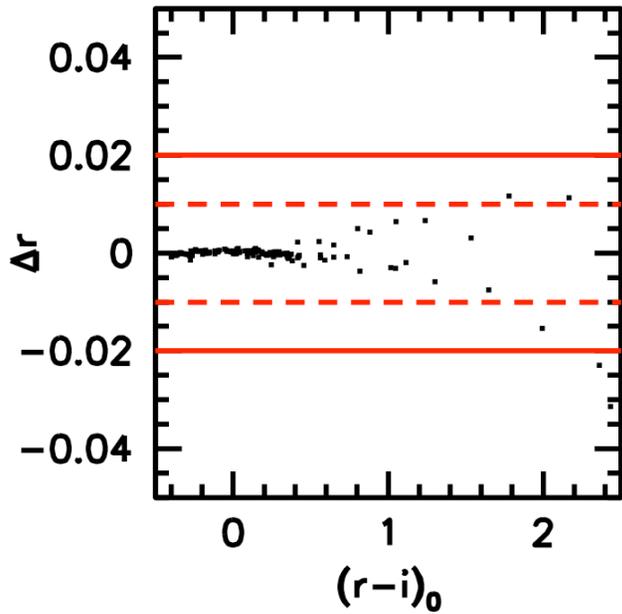
position 11 - position 7

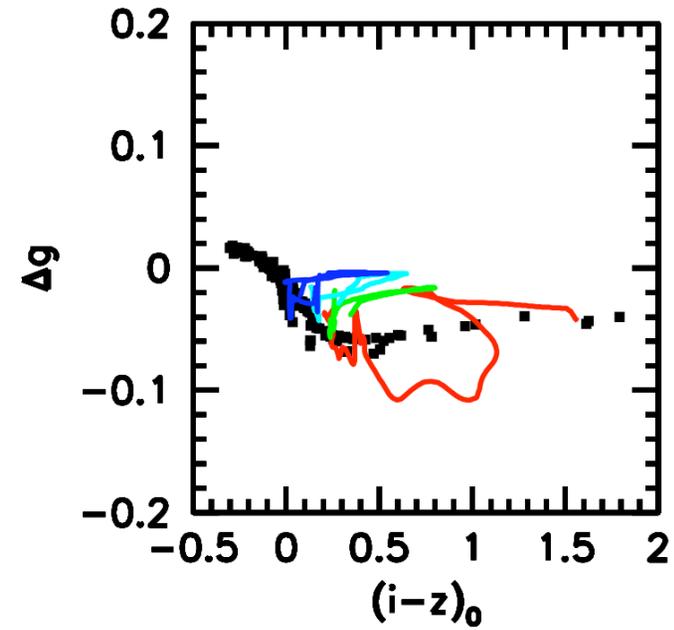
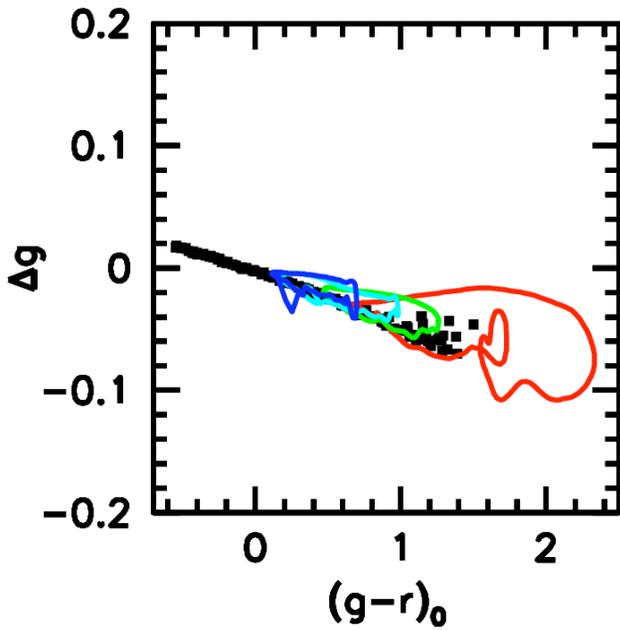
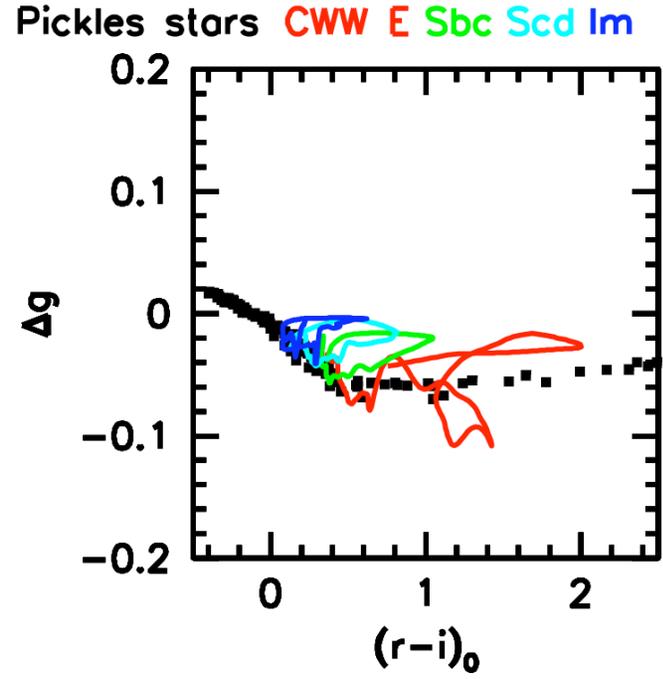
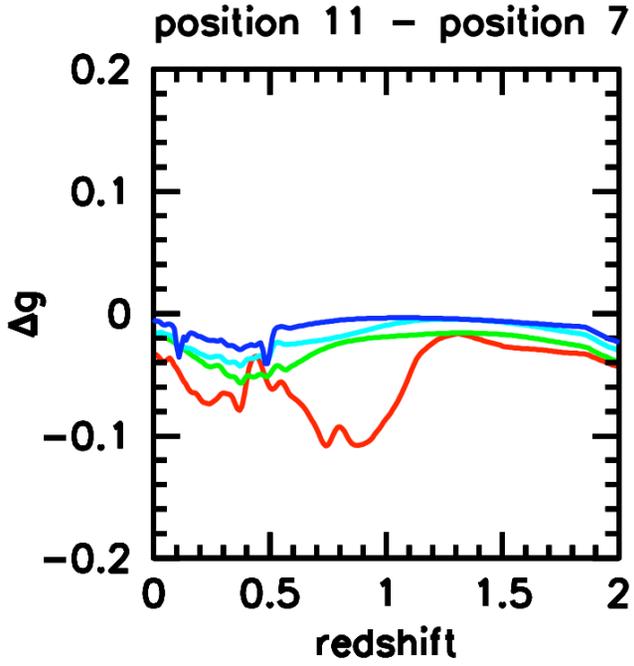


Pickles stars residuals

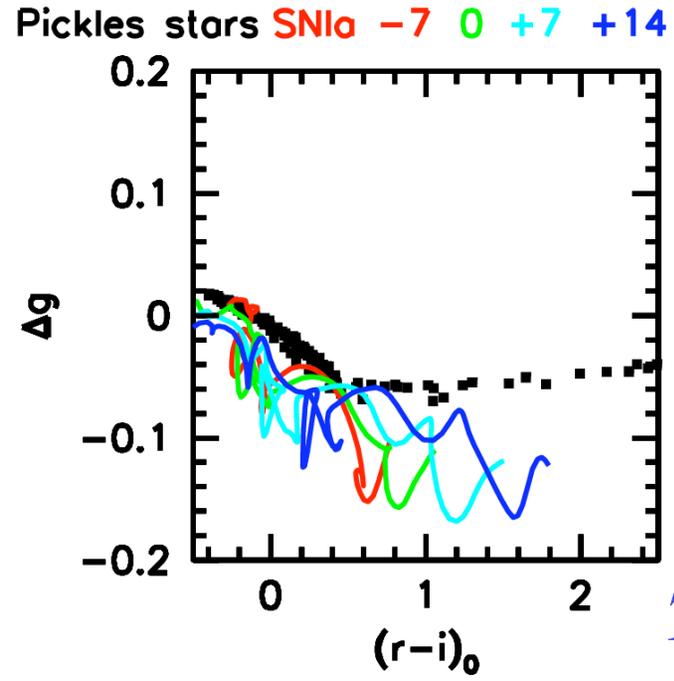
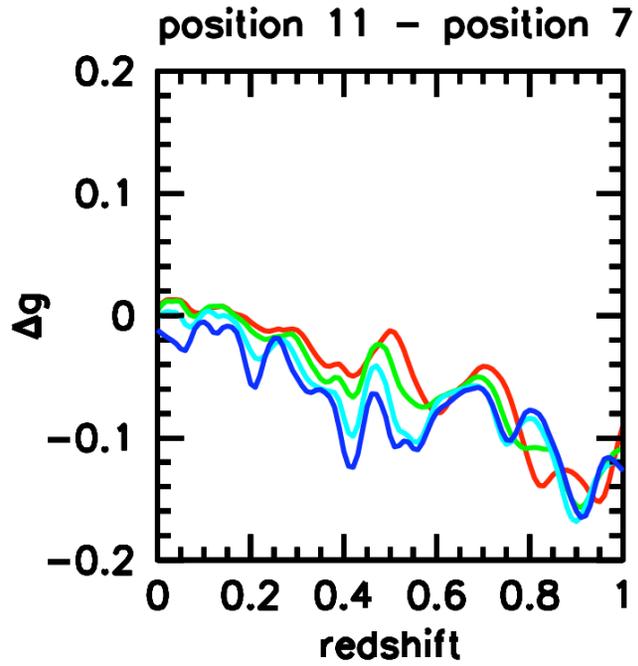


Stars

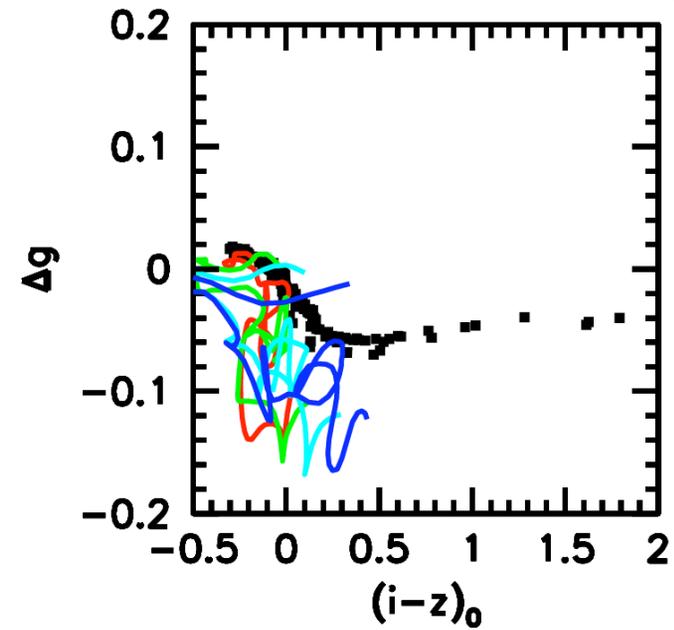
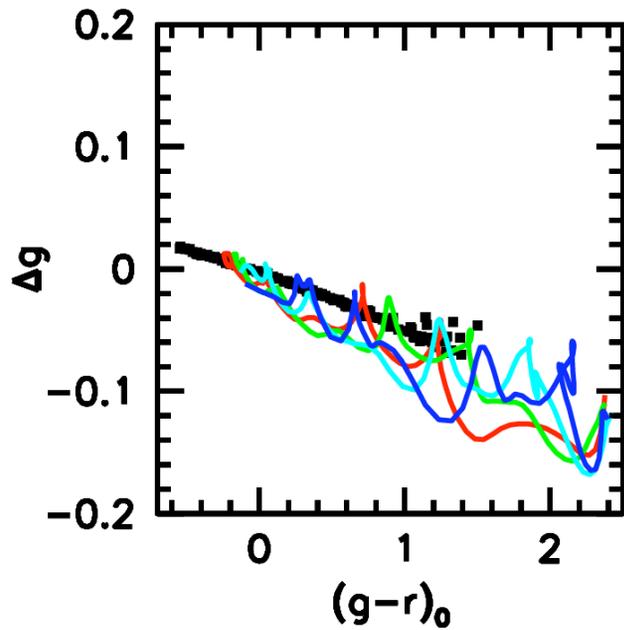




Galaxies

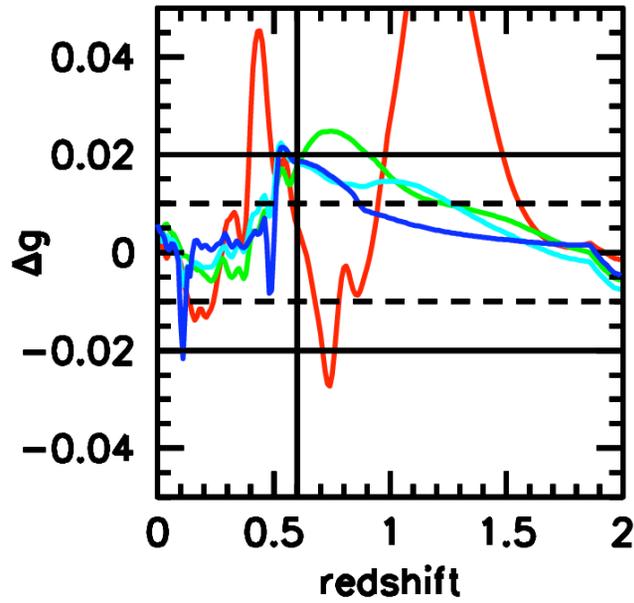


*Type Ia
Supernovae*



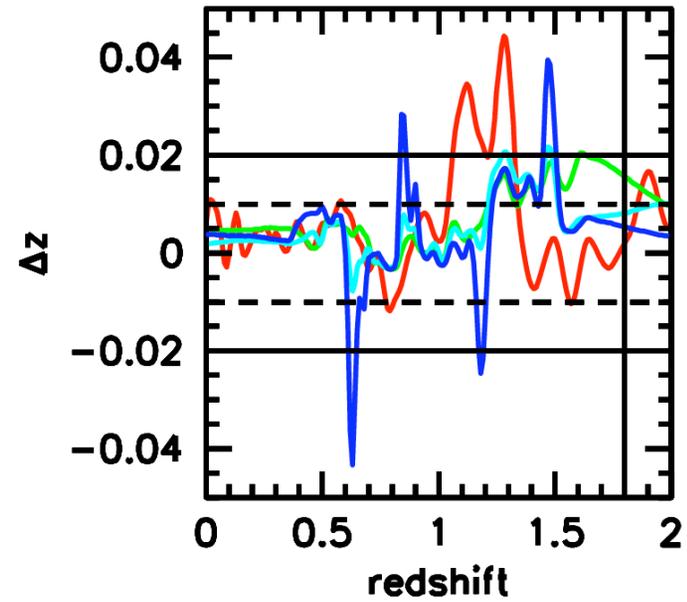
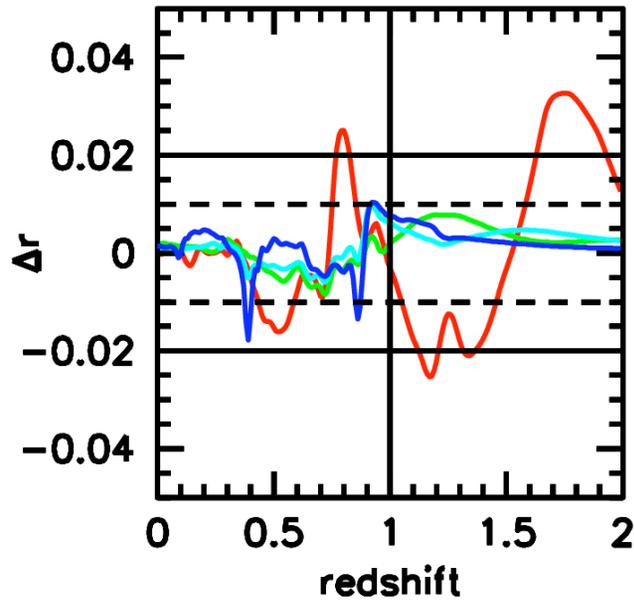
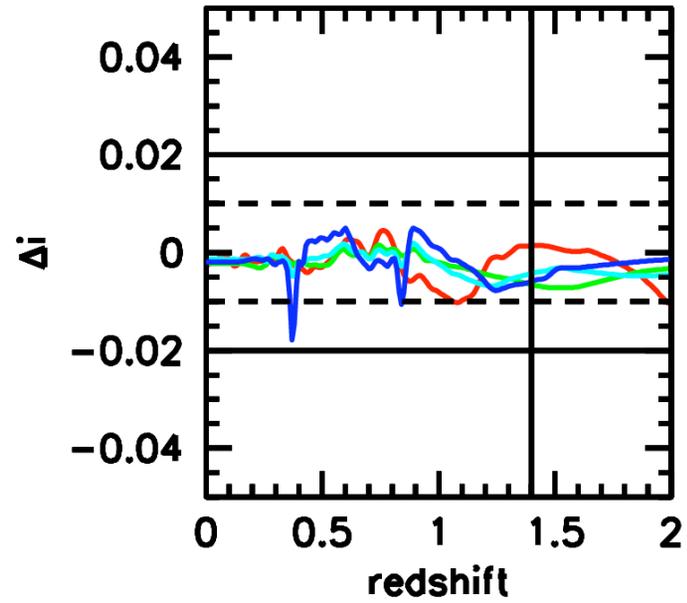


position 11 - position 7



residuals

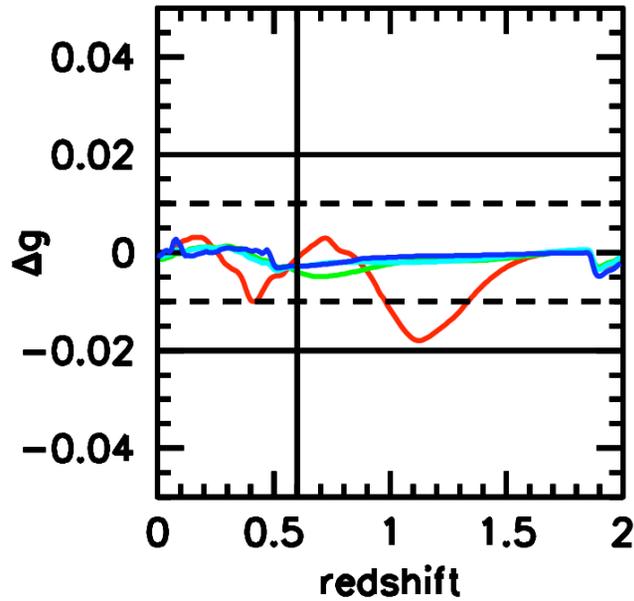
CWW E Sbc Im



Bad

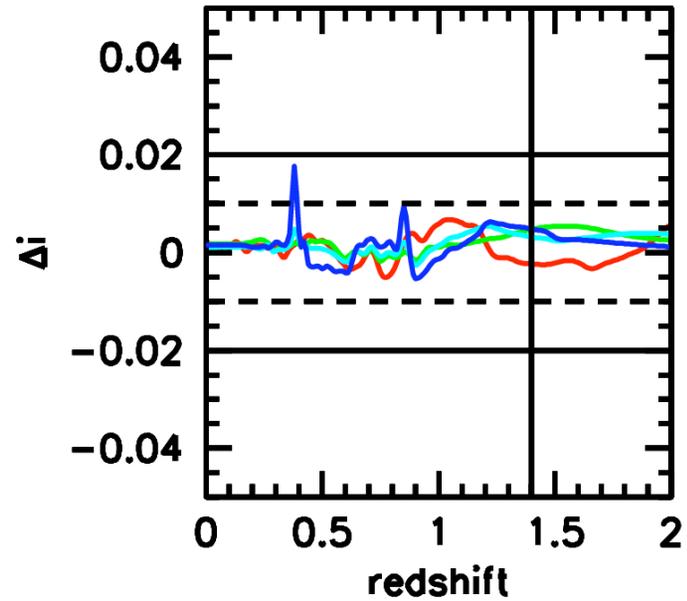


position 1 - position 7

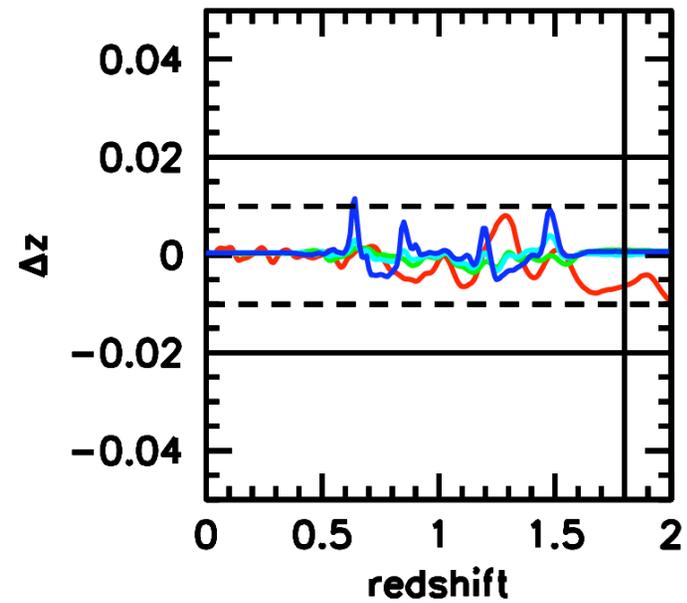
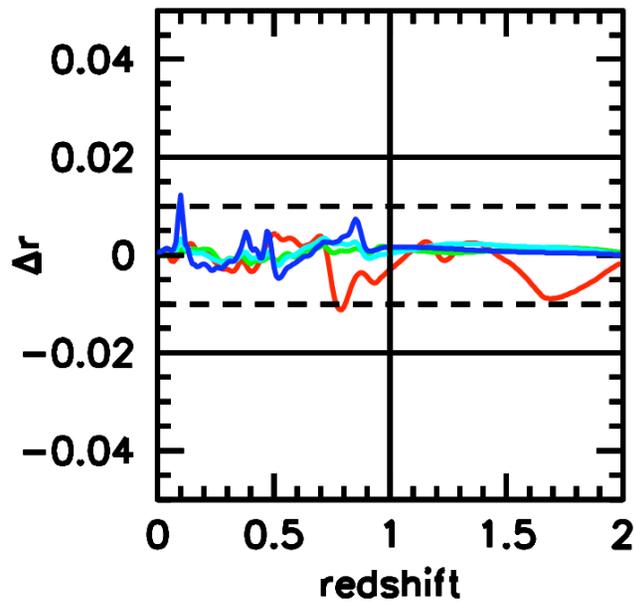


residuals

CWW E Sbc Scd Im

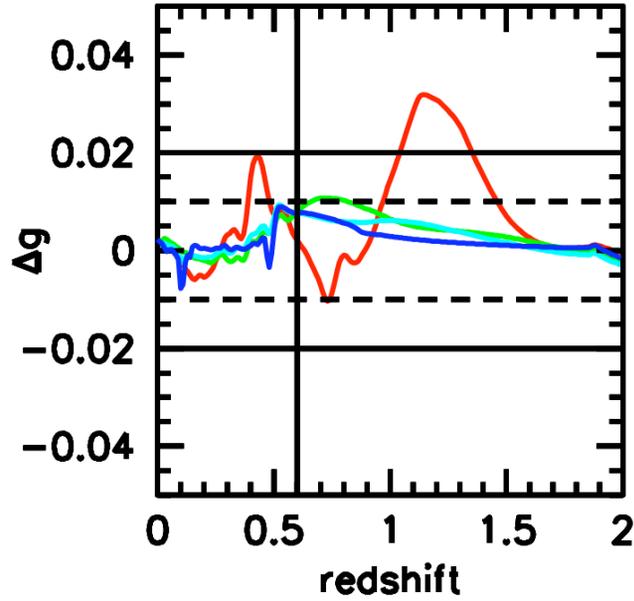


Good



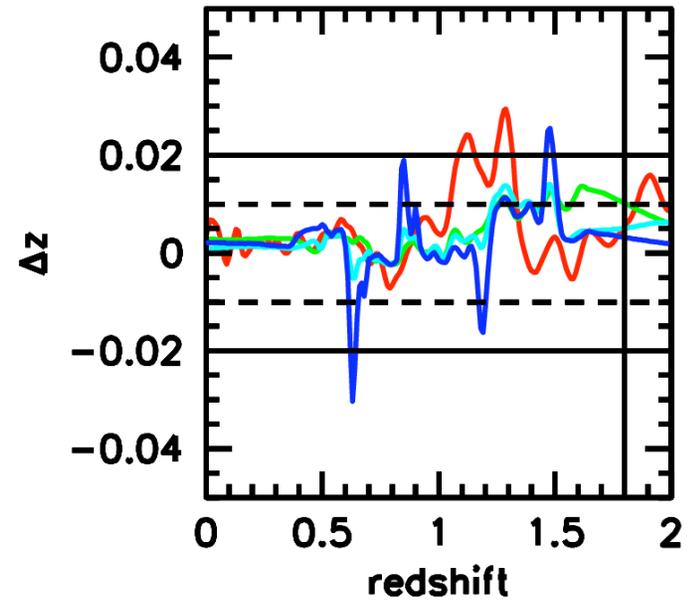
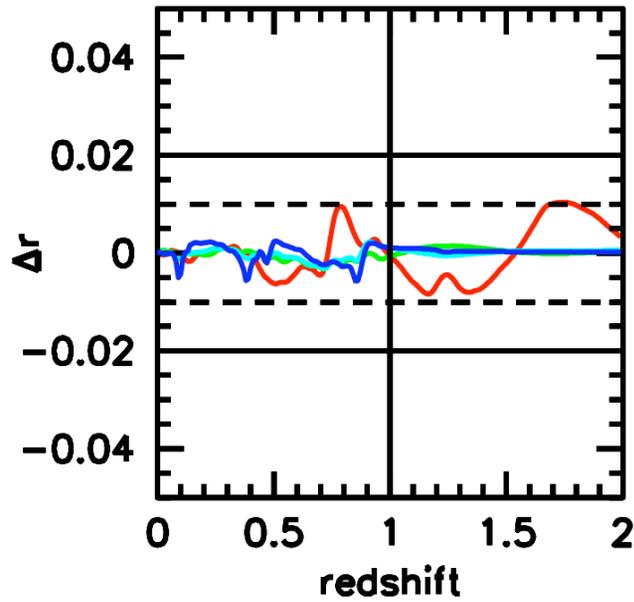
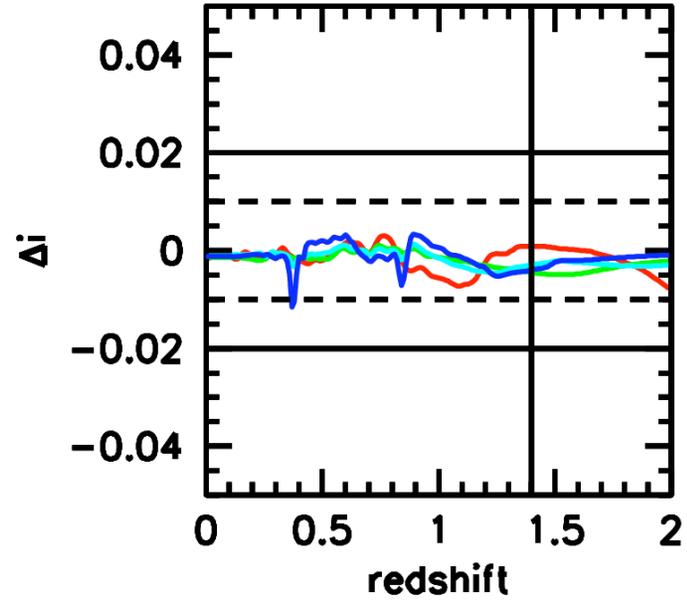


position 9 - position 7



residuals

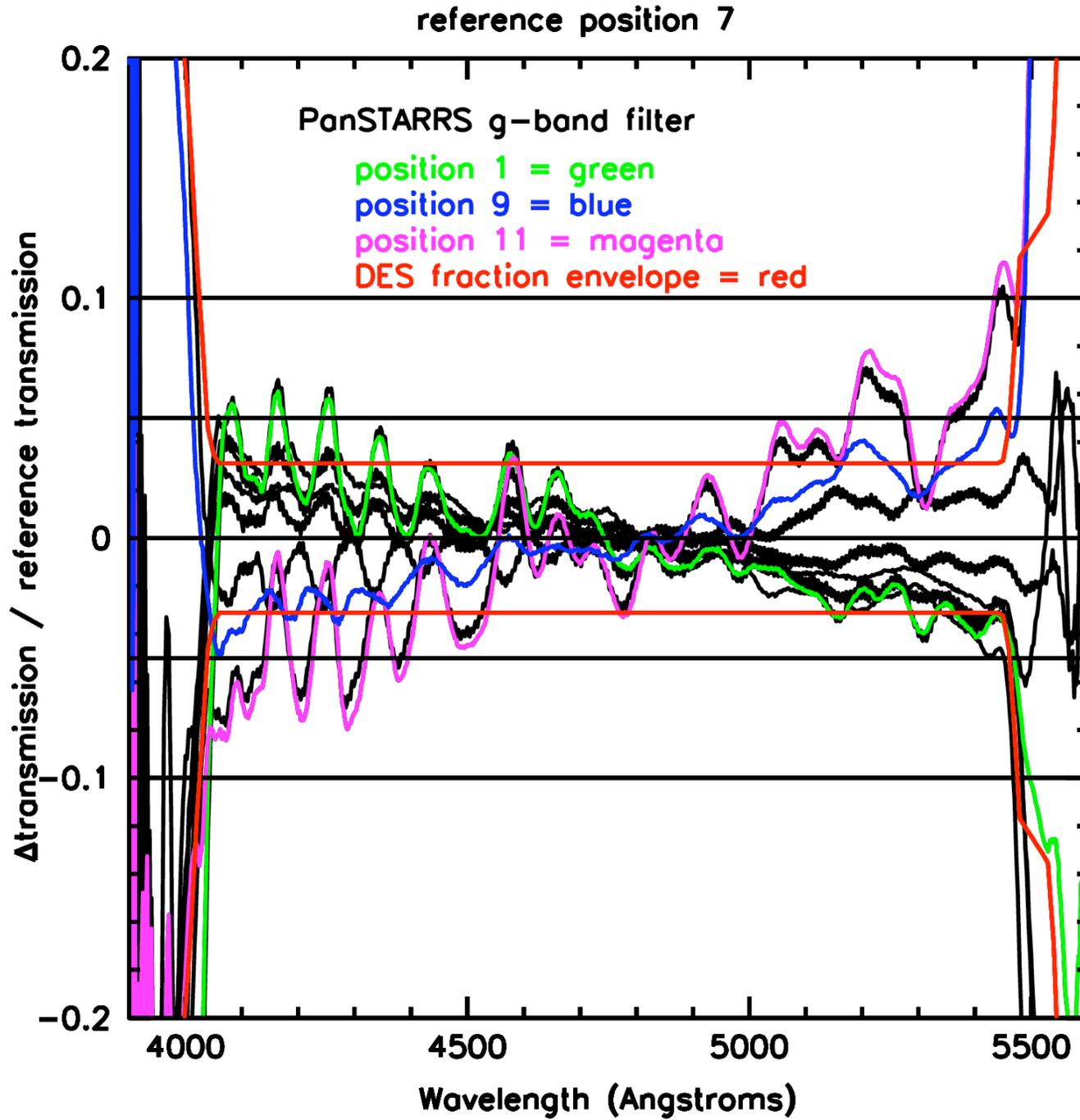
CWW E Sbc Im



Ok

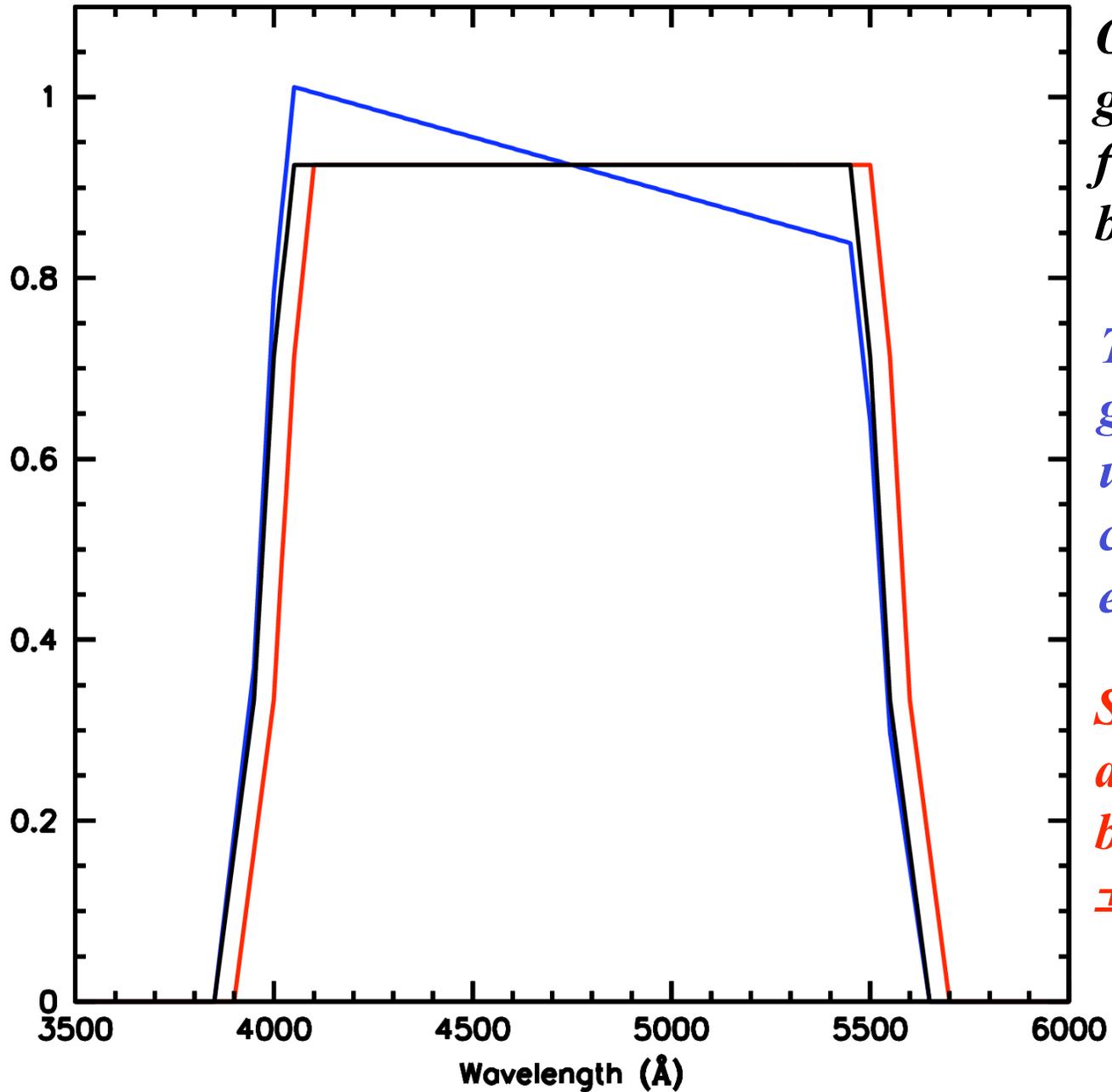


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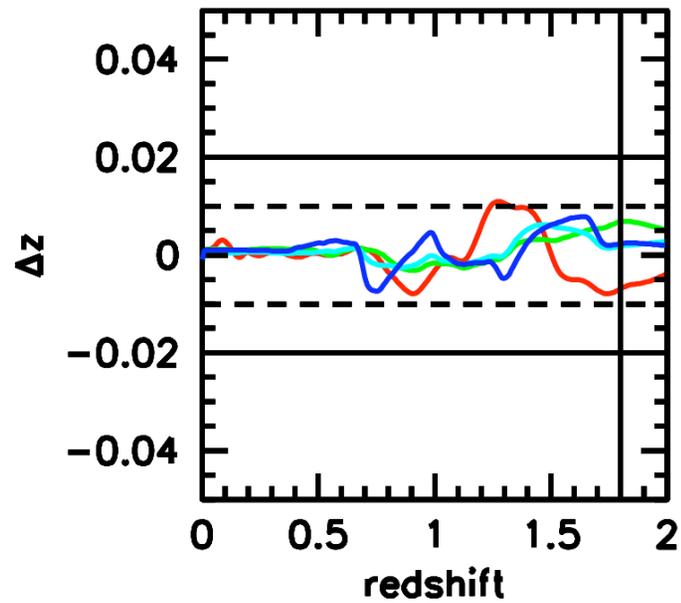
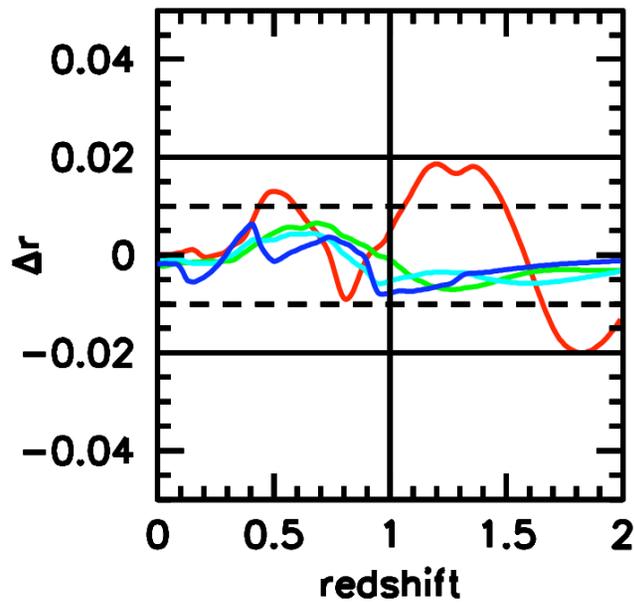
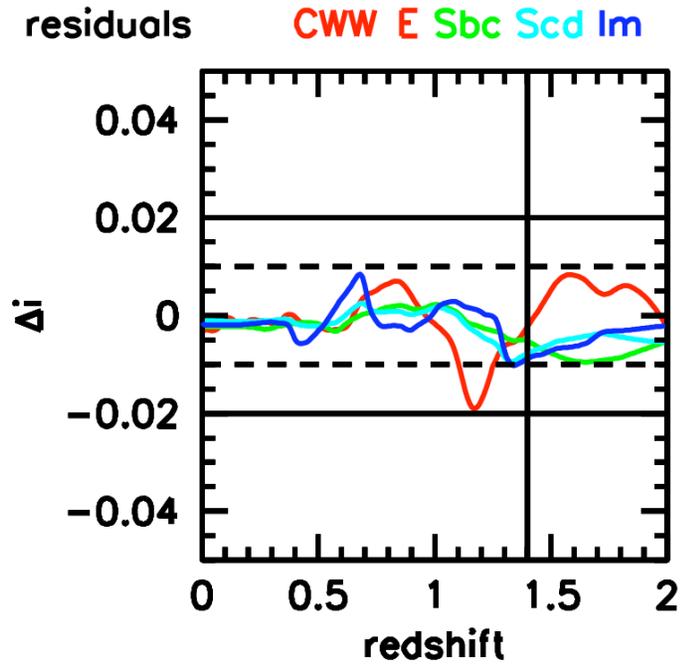
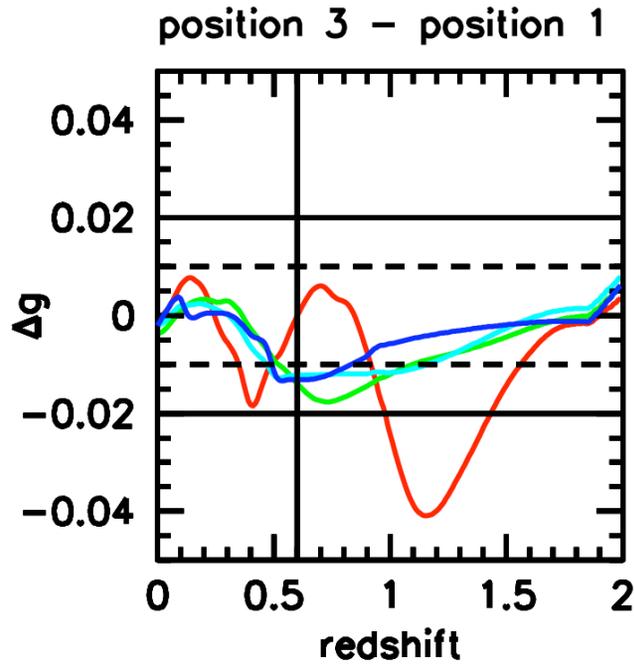
DARK ENERGY
SURVEY



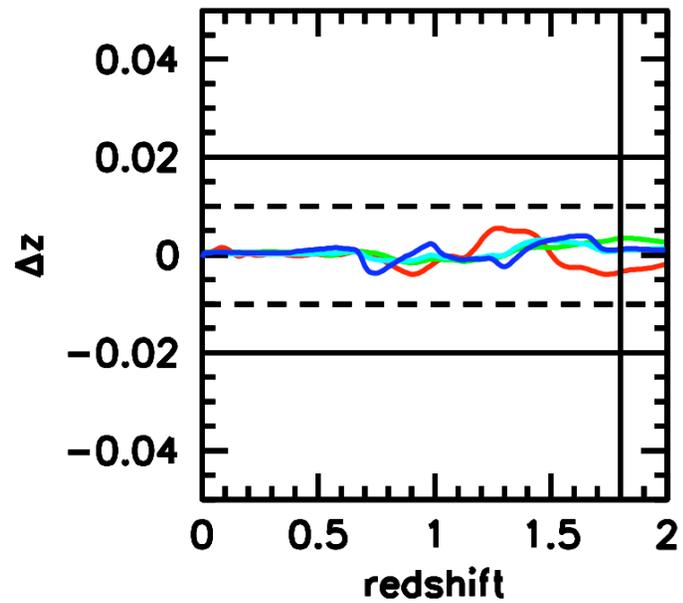
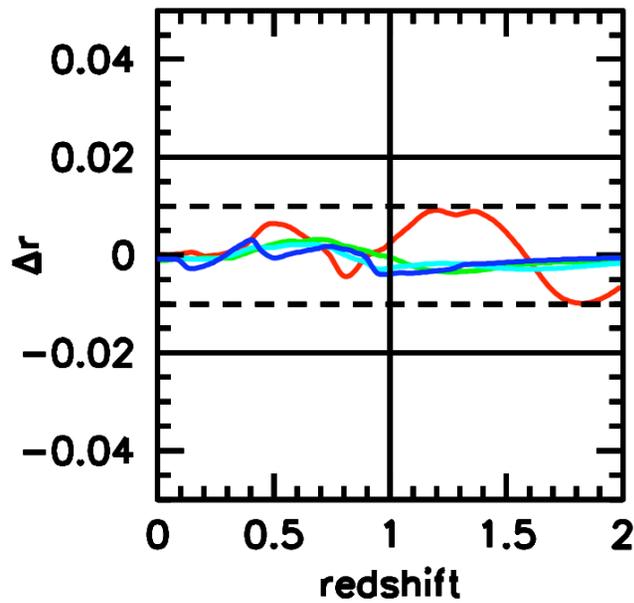
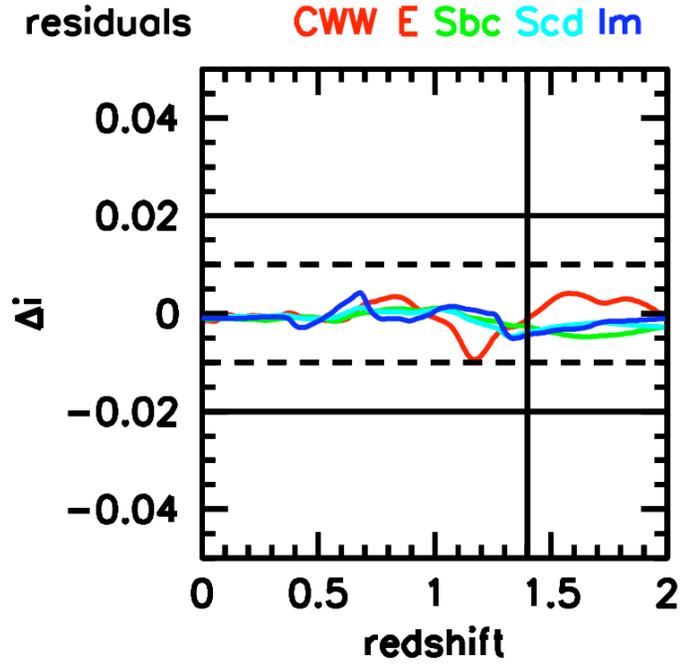
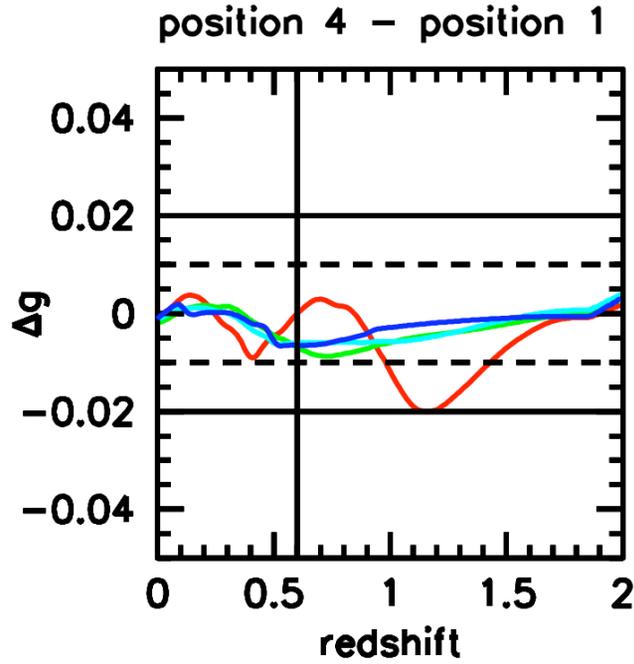
*Original
g-band
filter in
black*

*Tilt by
gradients of
up to $\pm 10\%$
center to
edge*

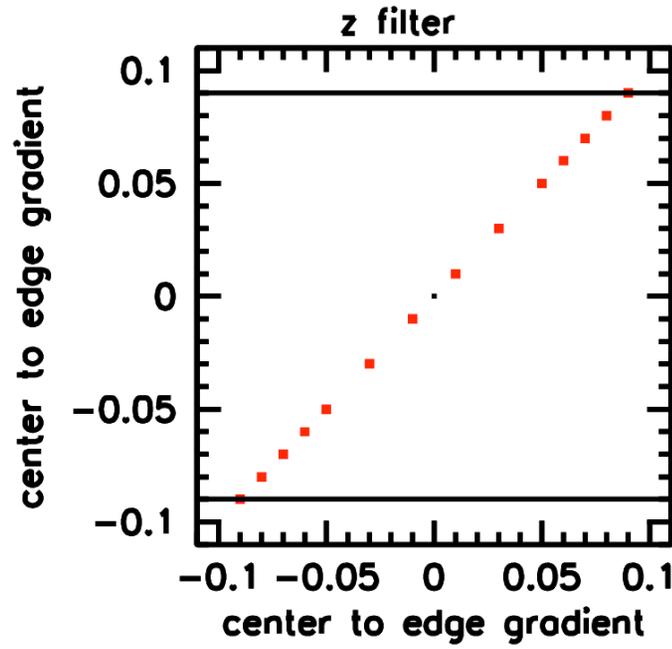
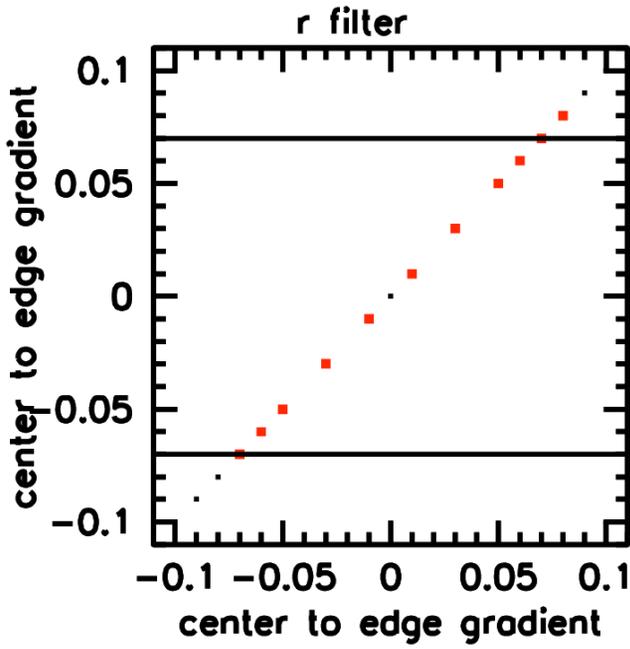
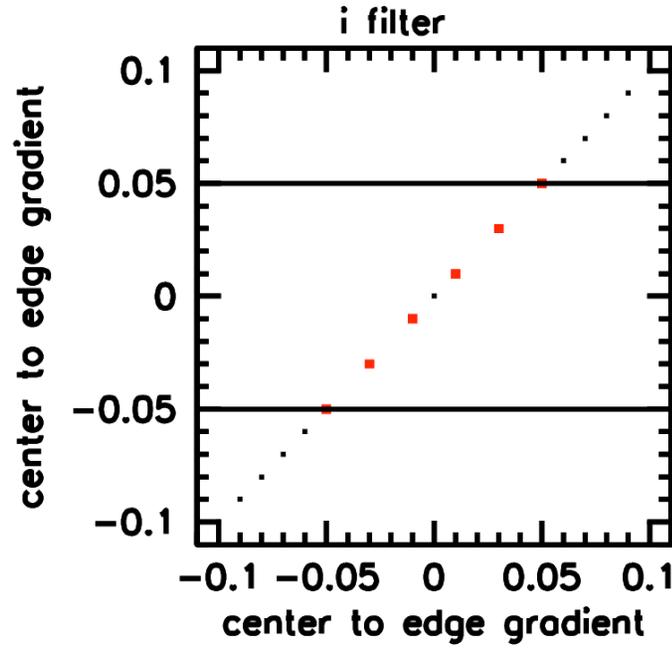
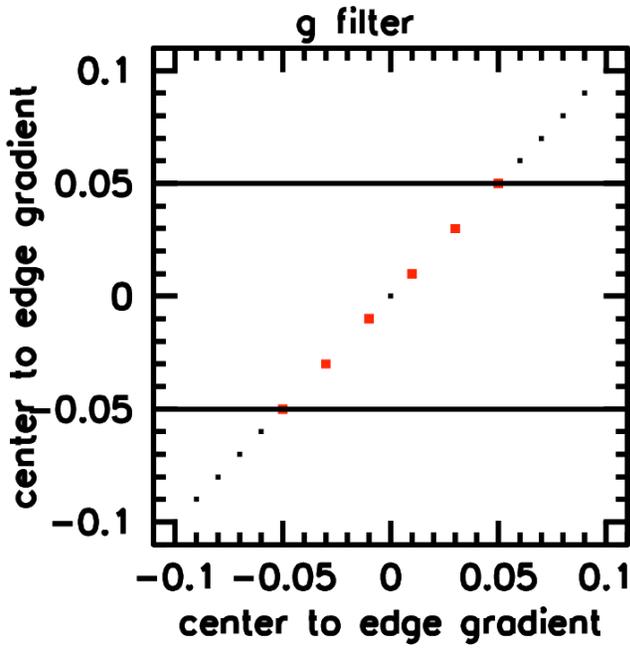
*Shift cut-on
and cut-off
by up to
 $\pm 50 \text{ \AA}$*



Galaxies
 $\pm 10\%$
gradient
filters



Galaxies
 $\pm 5\%$
gradient
filters



Gradients from filter center to edge

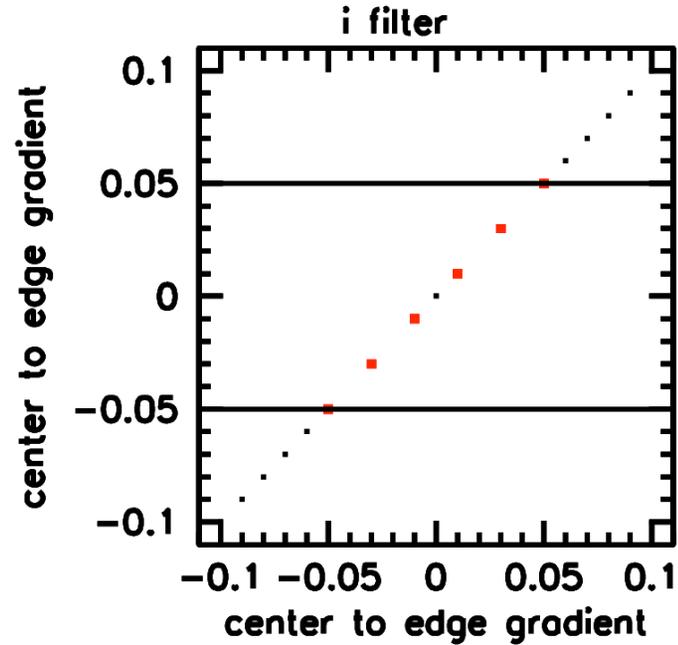
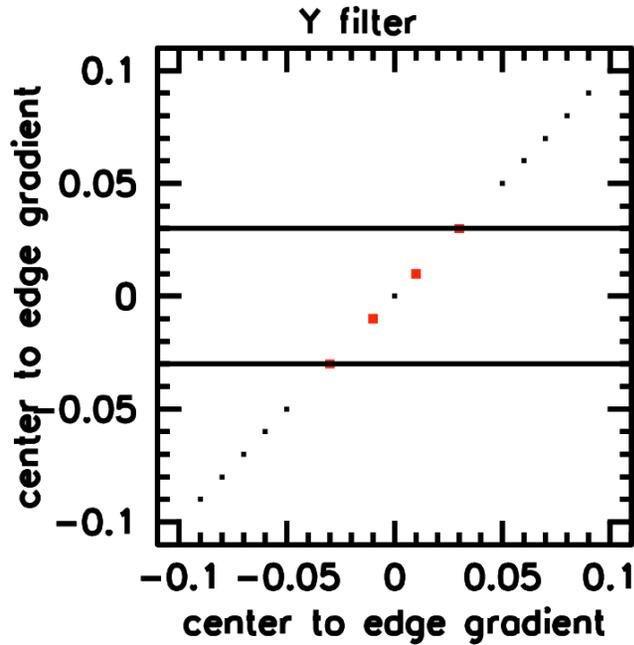
Red points indicate <1% flux errors for galaxies



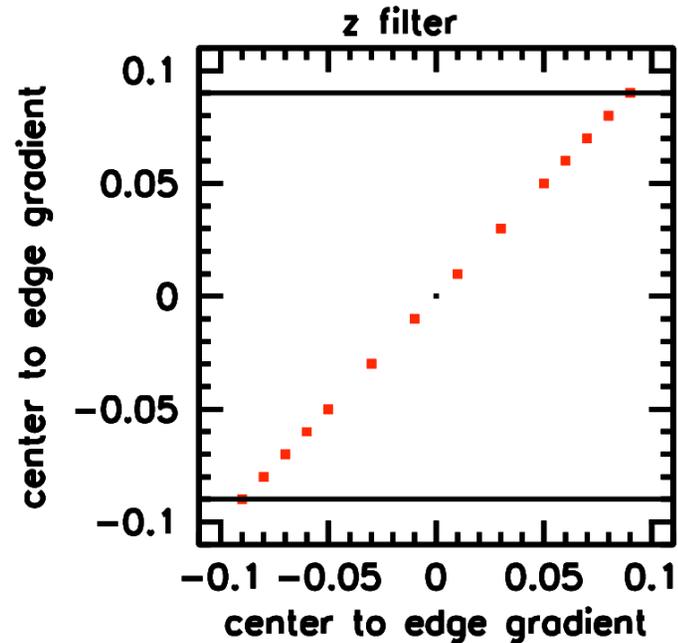
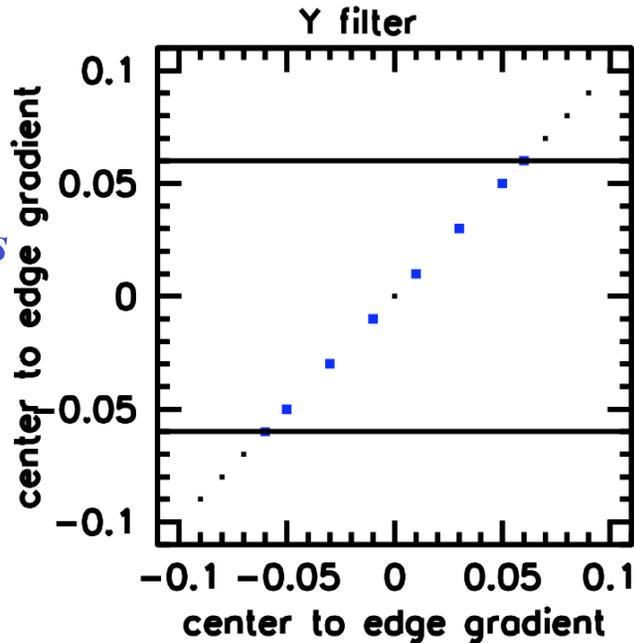
DARK ENERGY SURVEY

Red indicates <1% flux errors for Y

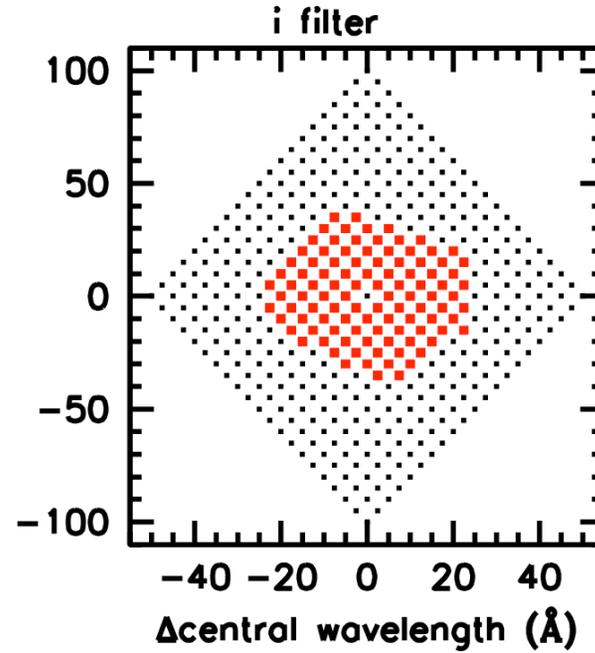
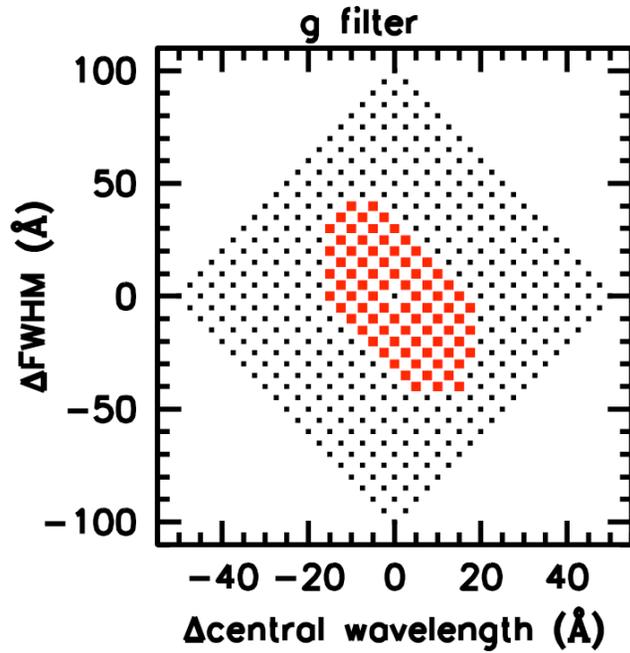
Blue indicates <2% flux errors for Y



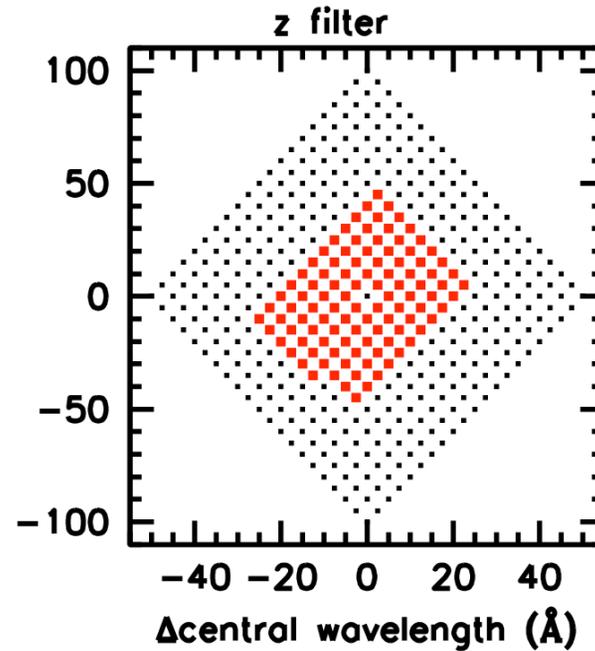
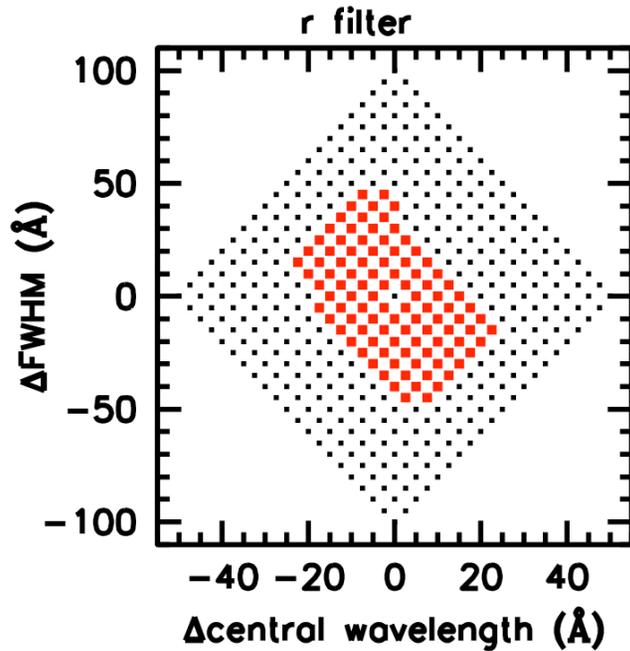
Gradients from filter center to edge



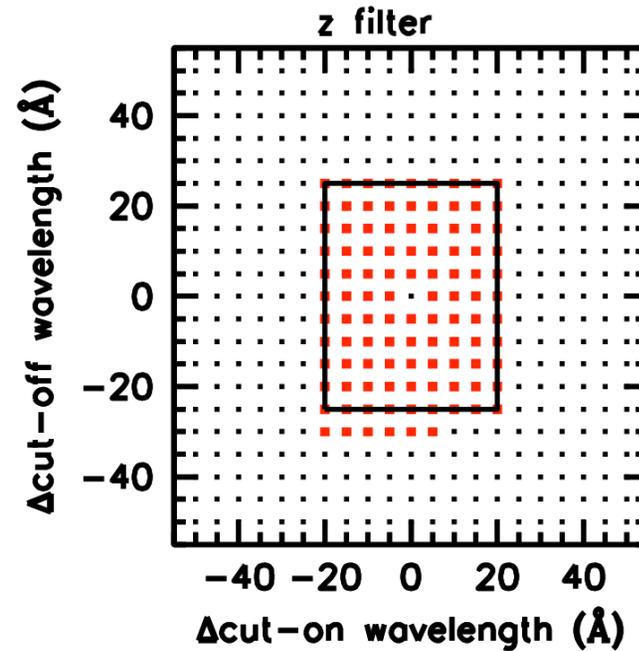
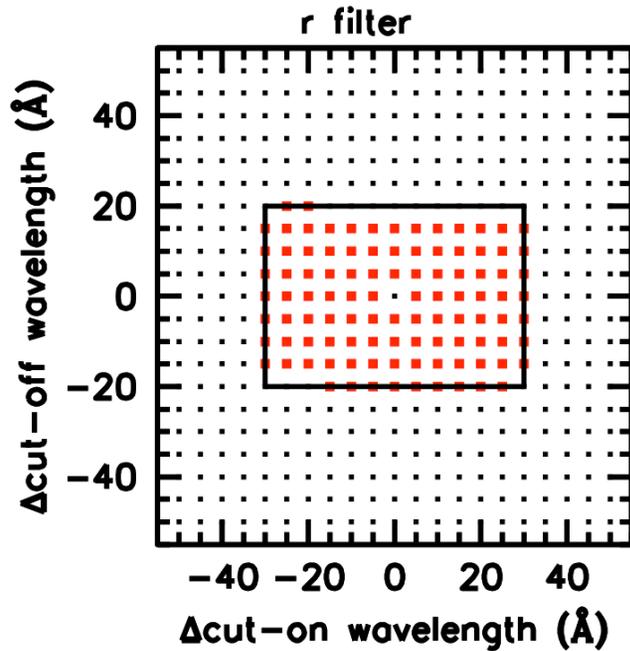
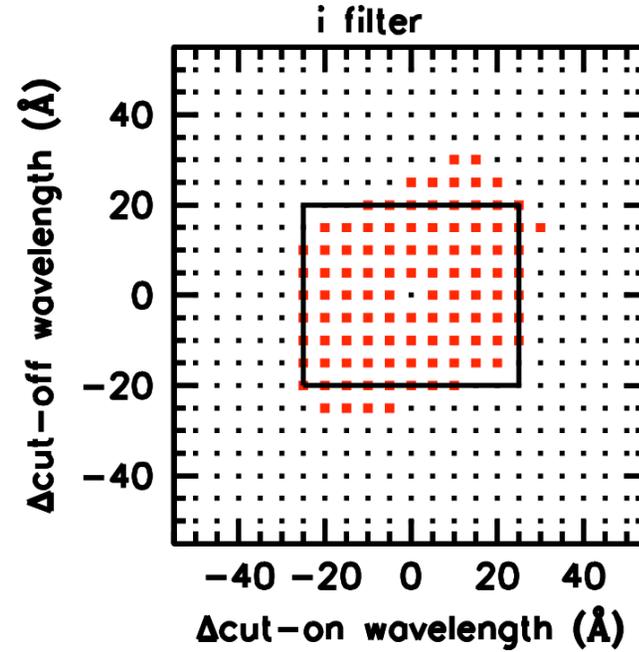
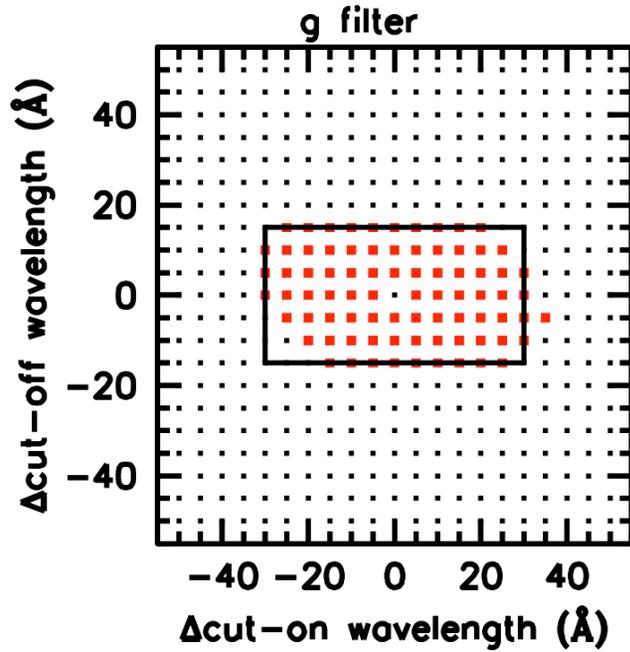
Red points indicate <1% flux errors for galaxies in i and z



*FWHM vs.
central
wavelengths*



*Red points
indicate
<1% flux
errors for
galaxies*



Cut-on vs. cut-off wavelengths (half-maximum points)

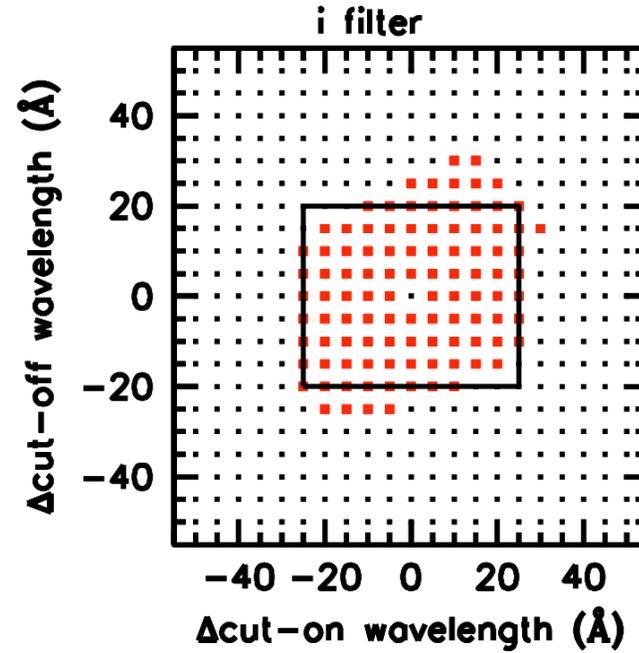
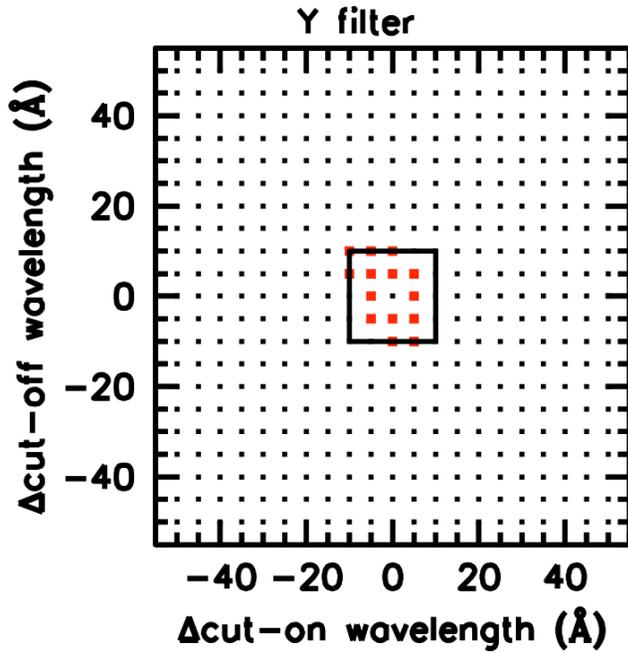
Red points indicate <1% flux errors for galaxies



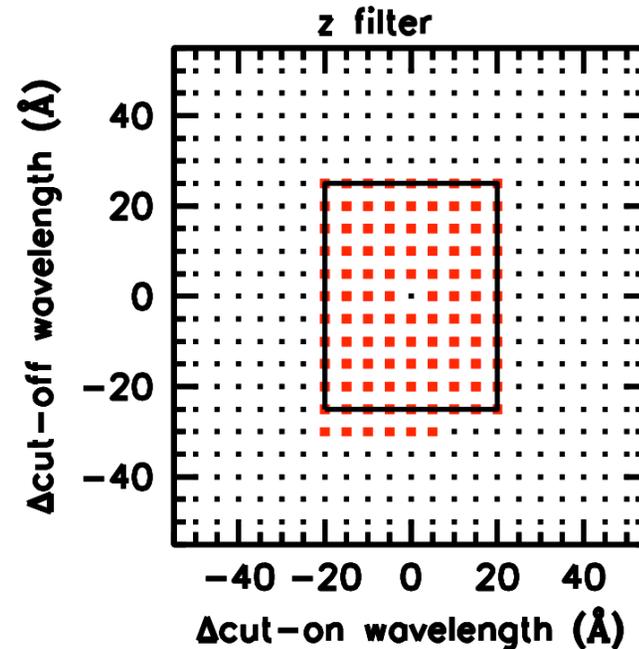
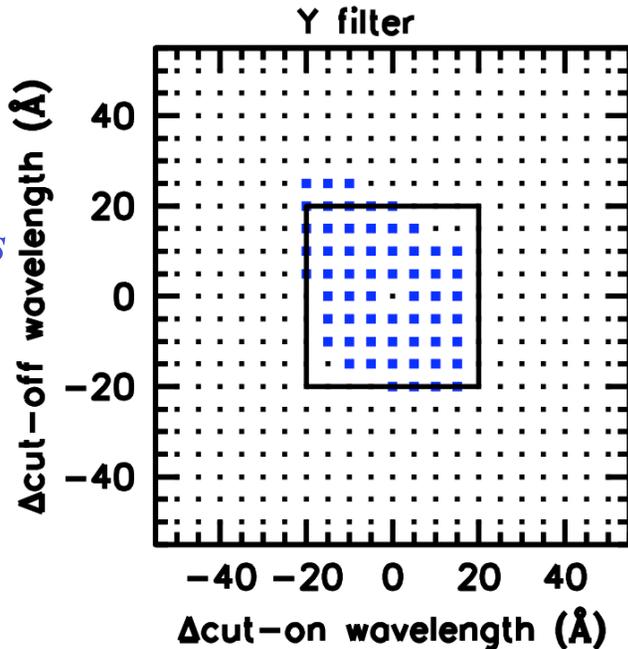
DARK ENERGY SURVEY

Red indicates <1% flux errors for Y

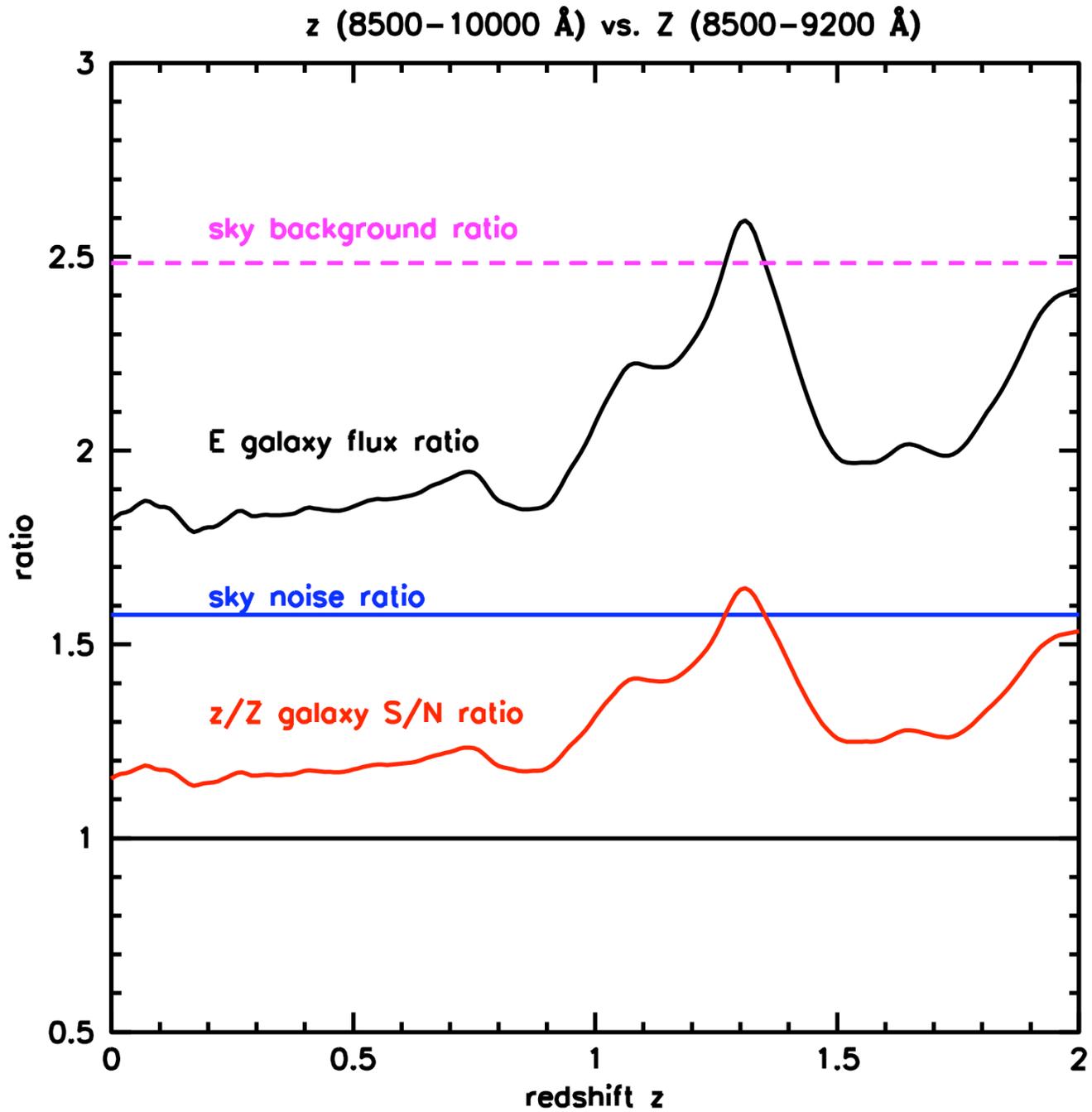
Blue indicates <2% flux errors for Y



Cut-on vs. cut-off wavelengths (half-maximum points)

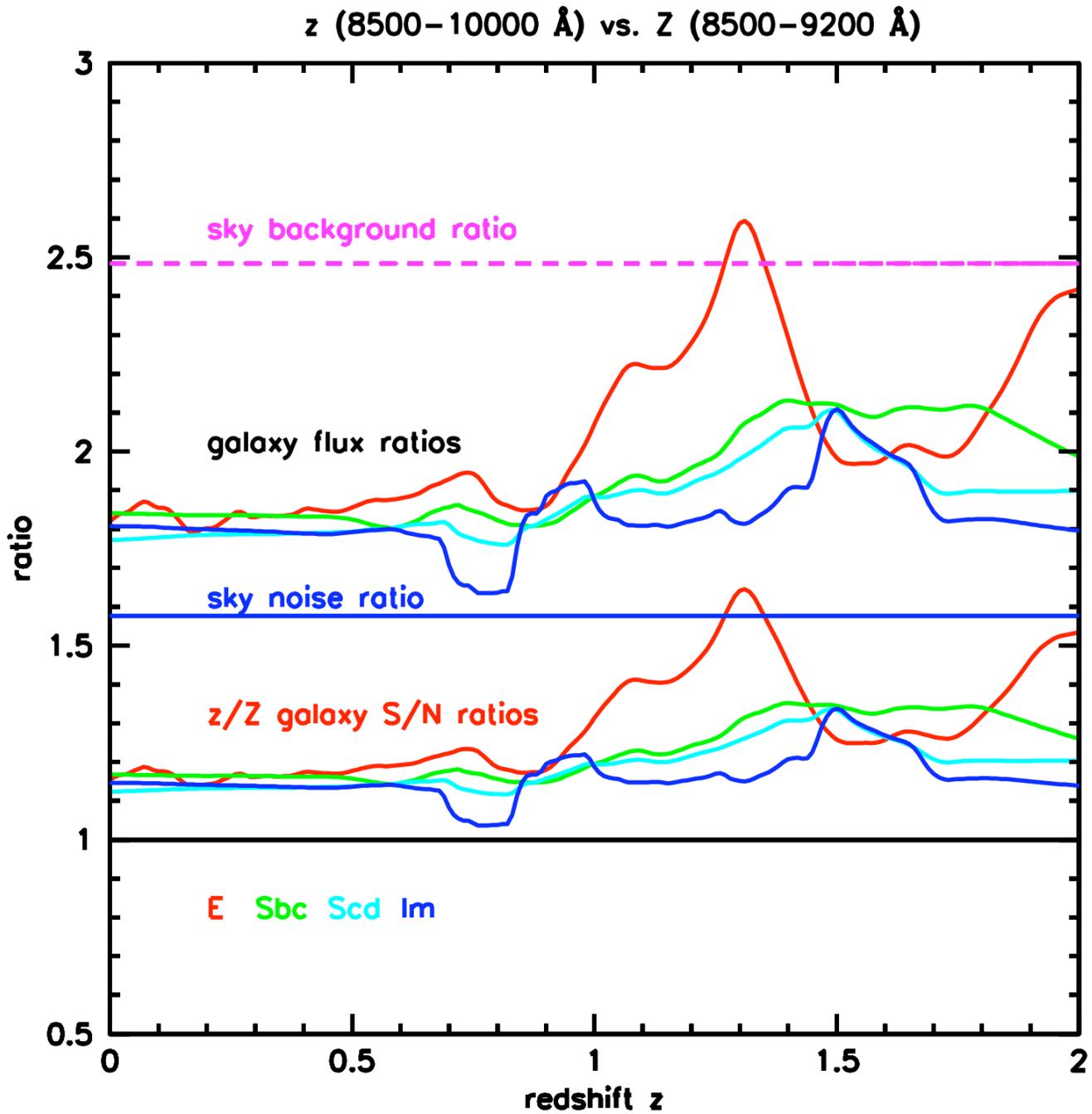


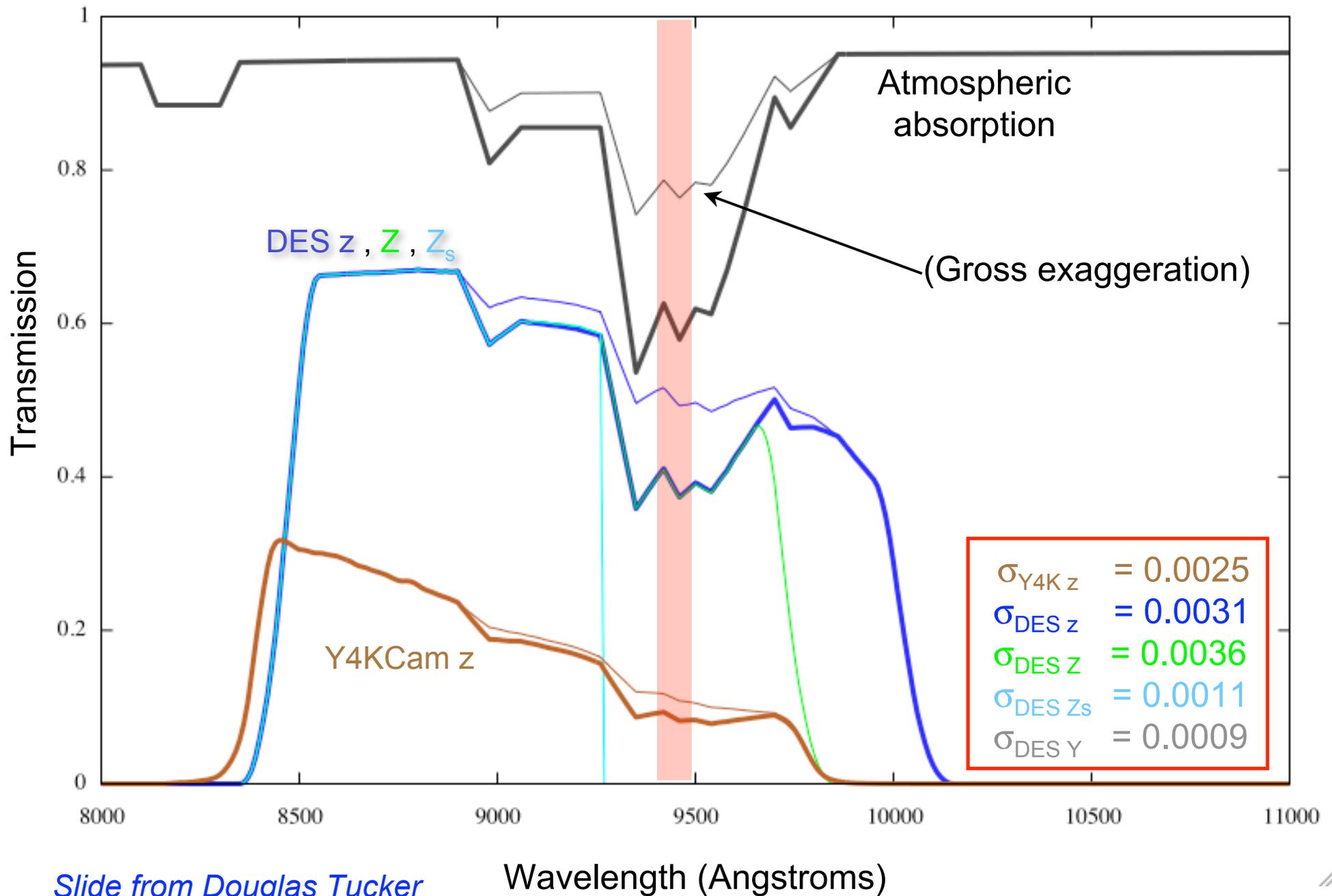
Red points indicate <1% flux errors for galaxies in i and z





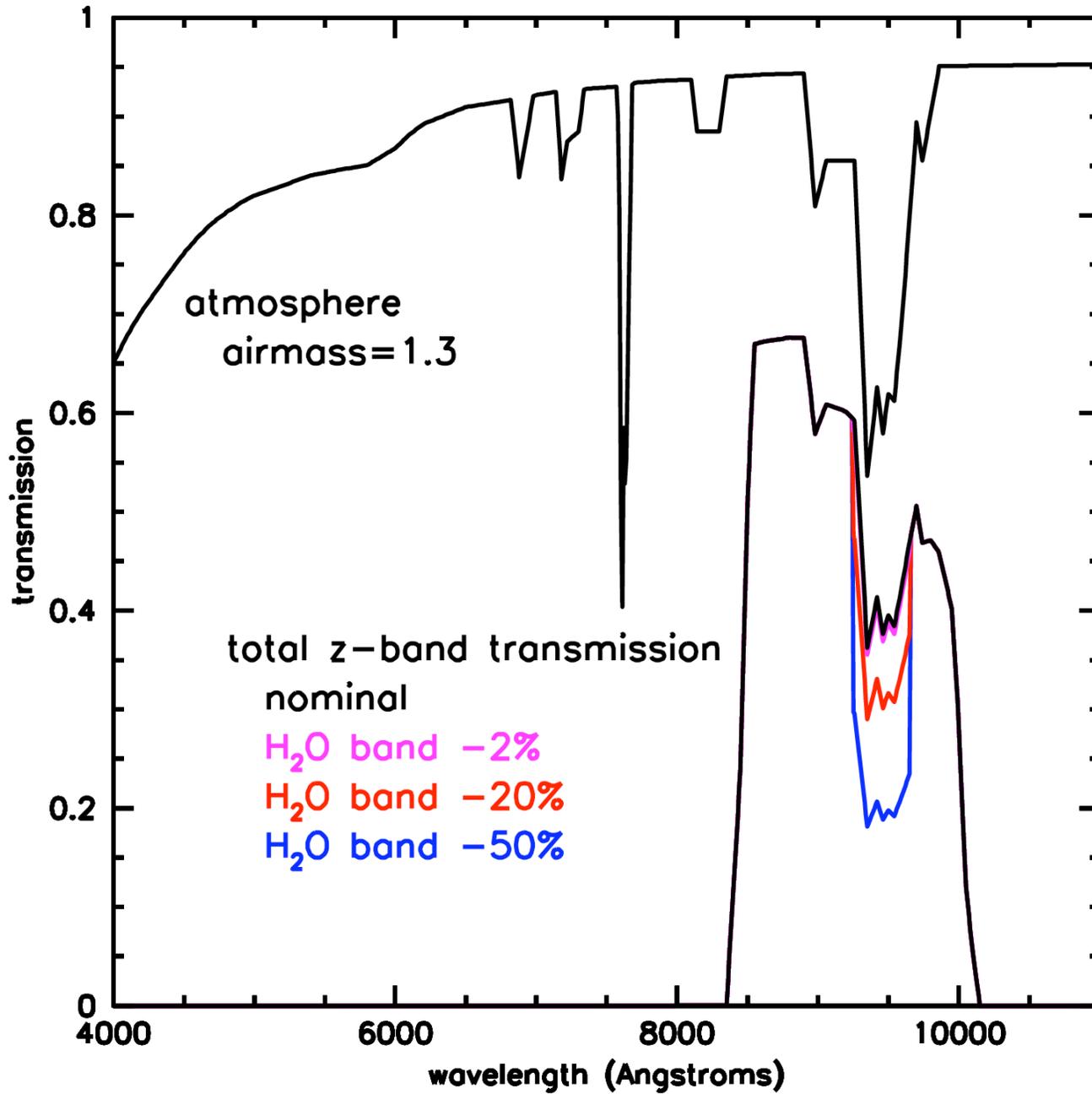
DARK ENERGY SURVEY

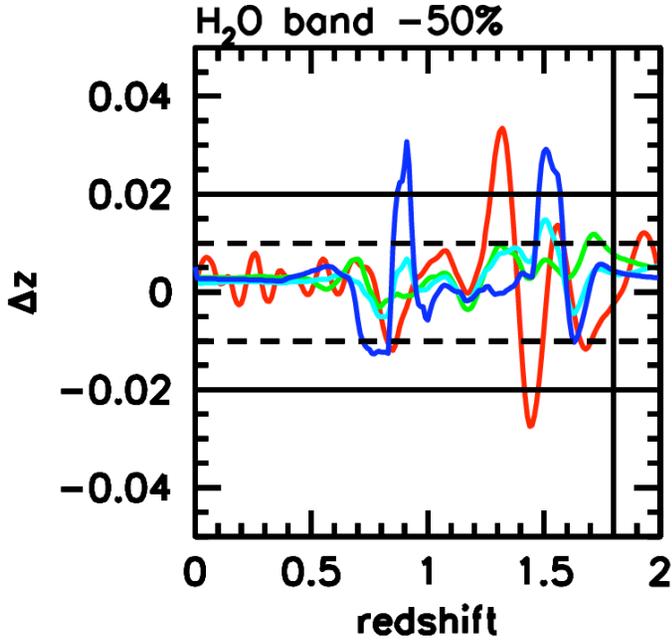
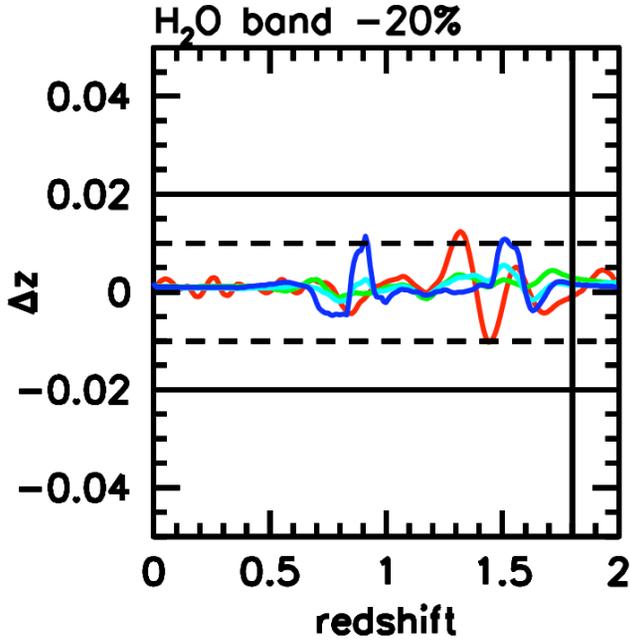
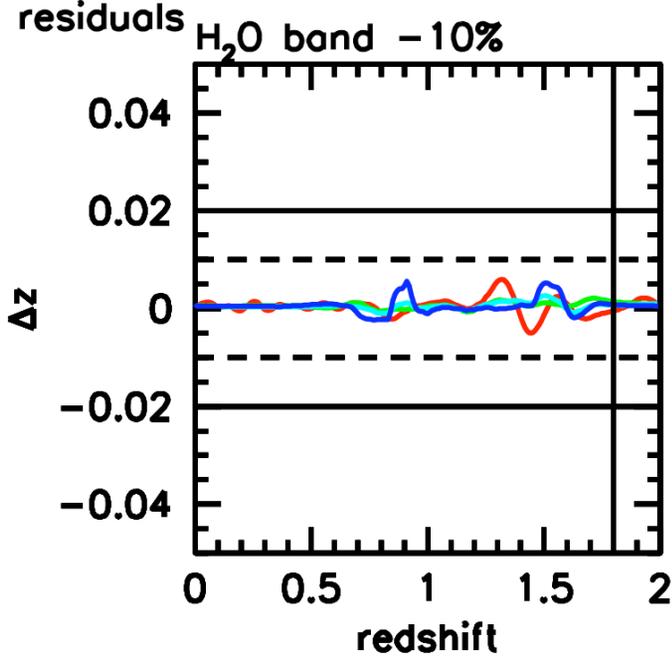
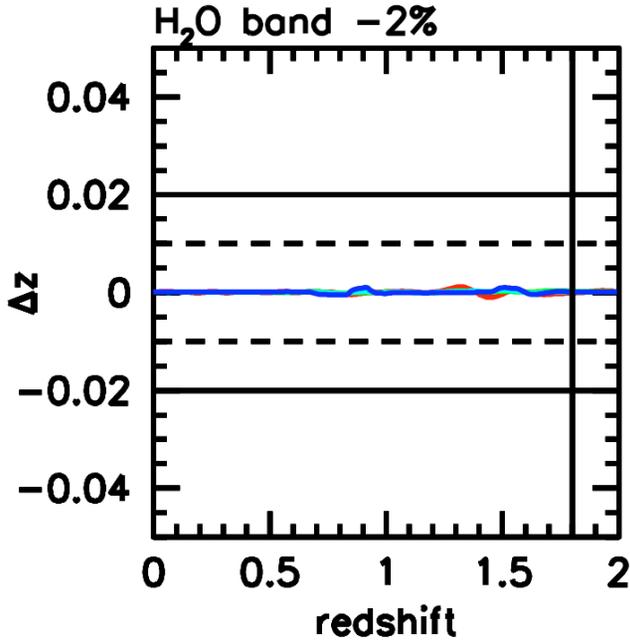






DARK ENERGY
SURVEY

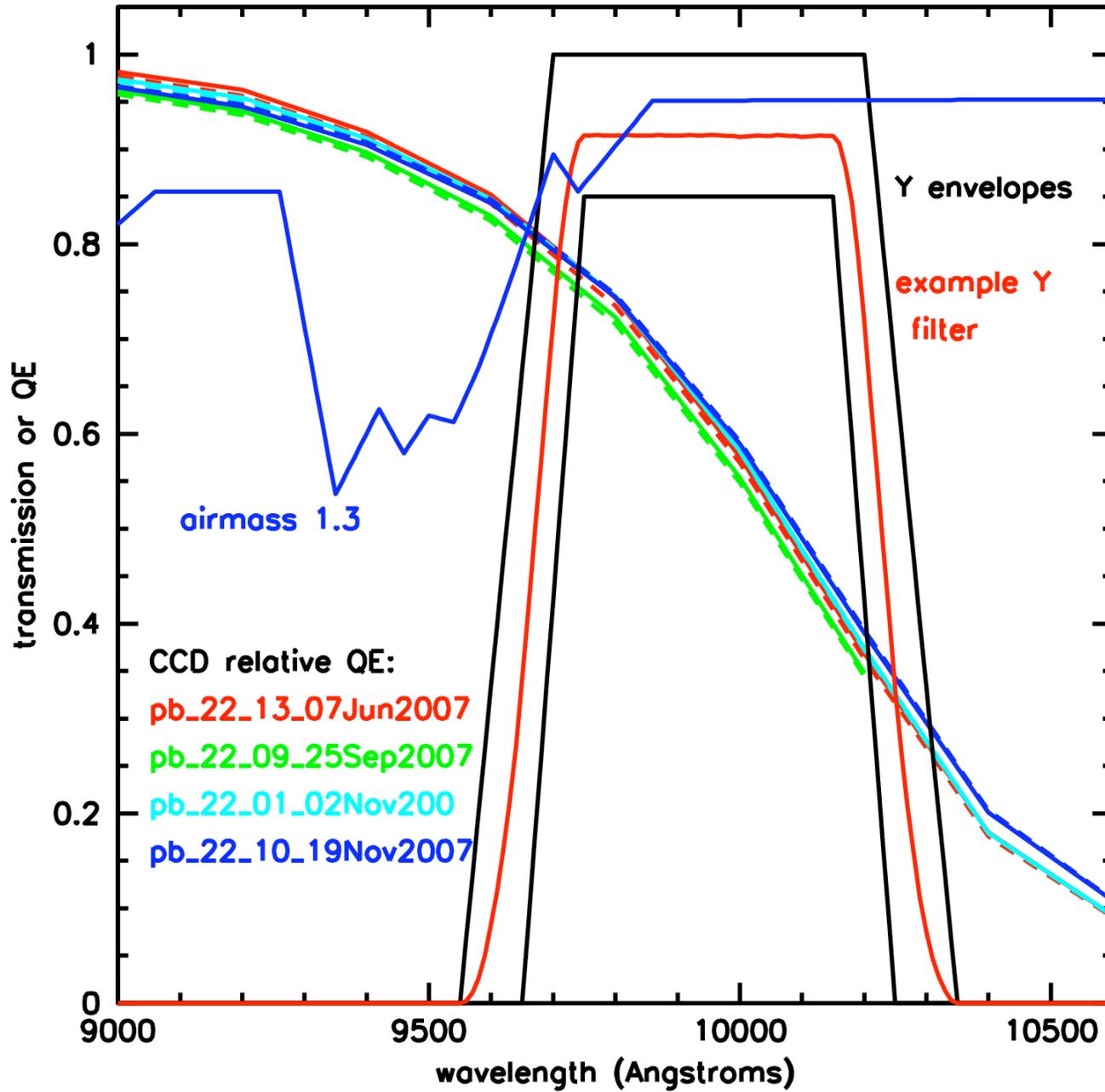




Galaxies
Color term
residuals for
2-50% less
transmission
in the H₂O
band

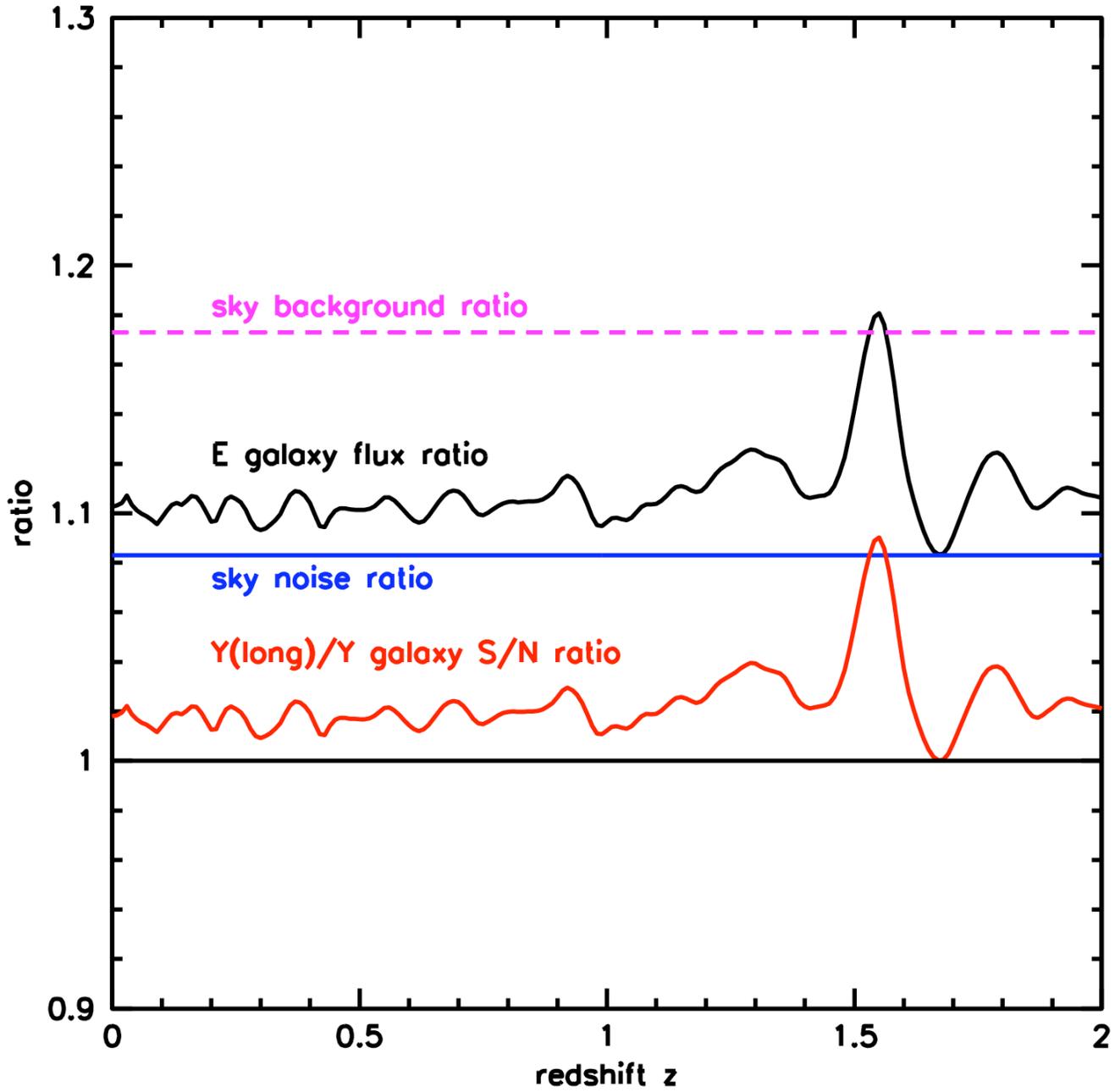


DARK ENERGY SURVEY





Y(long) (9700–10300 Å) vs. Y (9700–10200 Å)





DARK ENERGY
SURVEY

z/Z , Y Filter Summary

- **Recommend wider z (8500-10000 Å) over Z (8500-9200 Å)**
 - **Using z improves S/N about 20-50% vs. Z , for redshift 1-1.5 elliptical galaxy**
 - **Impact of water band variability**
 - **Residual photometric zeropoint fluctuations larger for z vs. Z , but estimated to be only ~0.3% from analysis of CTIO 1m data; is also taken out using relative photometry calibration**
 - **Color-term residuals are also small, even for exaggerated water band variability**
- **Y filter bandpass**
 - **Recommend 9700-10200 Å to cut off before CCD QE drops below ~20%**
 - **Extending red cutoff to 10300 Å (e.g., better matches LSST y) only gives S/N gain < 10% for $z > 1$ ellipticals**
 - **Recommend less stringent Y filter requirements giving 2% flux errors (instead of 1%), to make filter easier to manufacture**



DARK ENERGY
SURVEY

Conclusions

- **Keep same absolute transmission envelopes**
- **Relaxed transmission uniformity specifications possible, by using color terms based on stars, and applying to galaxies and SNe Ia**
 - **About 2-3 times less stringent than original ~3% uniformity specification when color terms not allowed**
- **Uniformity specifications to keep filter error contribution to < 1% (< 2% for Y)**

| Filter | Center-to-Edge Gradient | Cut-On | Cut-Off |
|---------------|--------------------------------|--|--|
| • g | $\pm 5\%$ | $\pm 30 \text{ \AA}$ | $\pm 15 \text{ \AA}$ |
| • r | $\pm 7\%$ | $\pm 30 \text{ \AA}$ | $\pm 20 \text{ \AA}$ |
| • i | $\pm 5\%$ | $\pm 25 \text{ \AA}$ | $\pm 20 \text{ \AA}$ |
| • z | $\pm 9\%$ | $\pm 20 \text{ \AA}$ | $\pm 25 \text{ \AA}$ |
| • Y | $\pm 6\%$ | $\pm 20 \text{ \AA}$ | $\pm 20 \text{ \AA}$ |
- **z and Y bandpasses as described on previous slide**



DARK ENERGY
SURVEY

Extra Slides



DECam Filter Wavelengths and Transmission Requirements

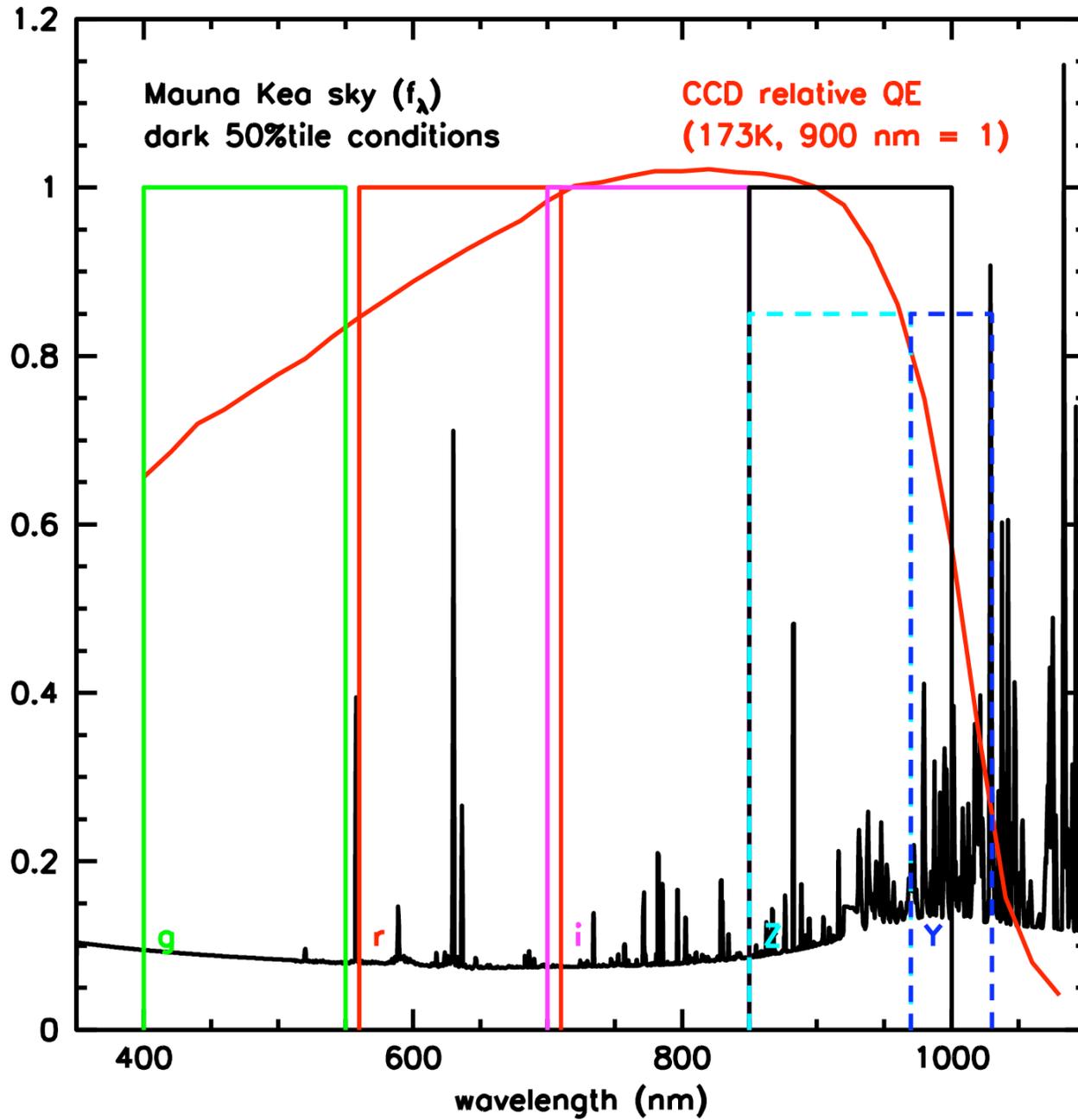
from DECam Technical Specifications (document #806)

- **TO.15 Filter transmission requirements: > 85% in [*g*, *r*, *i*, *z*]**
- **Table 3 Filter Transmission Requirements**

| filter | CWL (nm) | FWHM(nm) | Transmission |
|----------|----------|----------|--------------|
| <i>g</i> | 475 | 150 | 85% |
| <i>r</i> | 635 | 150 | 85% |
| <i>i</i> | 775 | 150 | 85% |
| <i>z</i> | 925 | 150 | 85% |



DARK ENERGY
SURVEY





DARK ENERGY
SURVEY

DECam Filter Specifications

from DECam Technical Specifications (document #806) and
DECam Filter RFI (document #1045)

Substrate dimensions: 620 mm diameter

Substrate material: fused silica

Minimum clear aperture: 610 mm diameter, concentric with substrate diameter

Total thickness: 13 mm

Surface parallelism: 30 arc-seconds or better

Bubble class: 0 (req. 0.1 mm² per 100 cm³; goal 0.03 mm² per 100 cm³)

Maximum bubble size: 0.5 mm diameter

Striae: requirement of 30 nm, goal of 20 nm

Pinhole limits: None with D > 60 microns; no more than one of the size 30-60 microns over an aperture of 50 mm, nor more than a combined equivalent area of 30 microns per 10 mm region of an aperture.

Surface quality: 80-50 scratch-dig

Durability: Mil-C-48479 (moderate abrasion)

Surface quality: Filter edges are to be sealed to prevent moisture incursions into the substrate

Radioisotope limits in filter substrate: U<0.8 ppm, Th<2.5ppm, K<0.03% (by weight)

Radioisotope limits in filter coatings: U<80 ppm, Th<250ppm, K<3% (by weight)



DARK ENERGY
SURVEY

DECam Filter Specifications (cont'd)

from DECam Technical Specifications (document #806) and

DECam Filter RFI (document #1045)

Operating focal ratio: f/2.9

Optical thickness: All filters shall have the same optical thickness, ± 0.10 mm air equivalent.

Transmitted wave error in 125 mm diameter sub-aperture: $< \lambda/4$

Beam Angles of Incidence: 0 – 4 degrees for f/2.9 beams (maximum range 0-12 deg)

Coatings: All air-glass interfaces are to be anti-reflection (AR) coated.

Predicted performance of the AR coatings should be provided with the quotation.

Filter substrate edges to be sealed against moisture penetration.

Transmission: Specified by absolute transmission envelopes vs. wavelength,
and spatial uniformity specified by “fraction envelopes” (see later this talk)

Normal operating temperature: -5C to 27C

Survival temperature range: -56C to 40C

Normal operating humidity range: 0-60% (dry nitrogen environment)

Survival humidity range: 0-100%

Normal operating elevation: 2200 m (7220 ft)

Normal operating pressure: 570-590 Torr

Operational lifetime: 10 years



Top Level Photometric Calibration Science Requirements (version 6.5 draft of document)

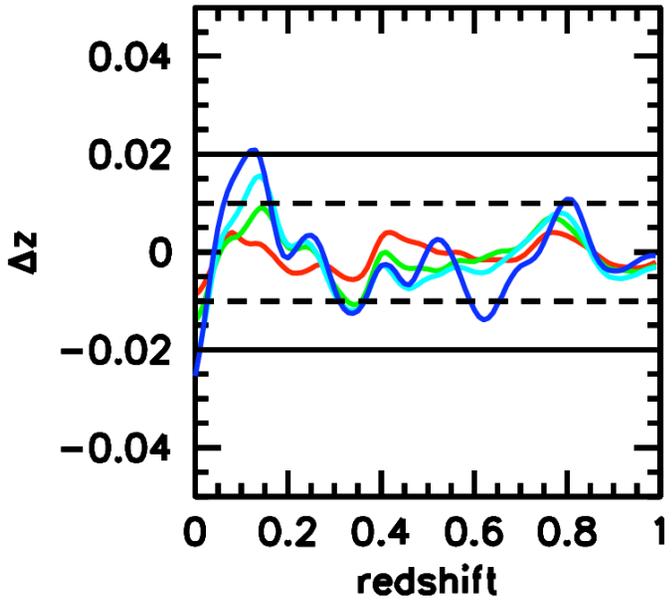
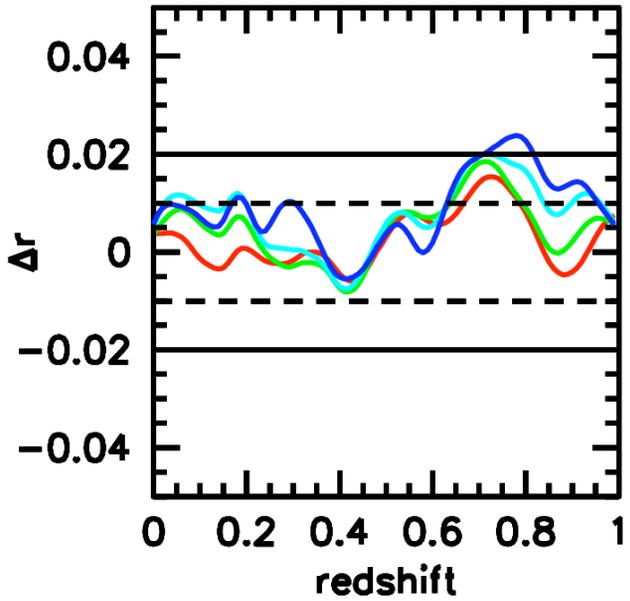
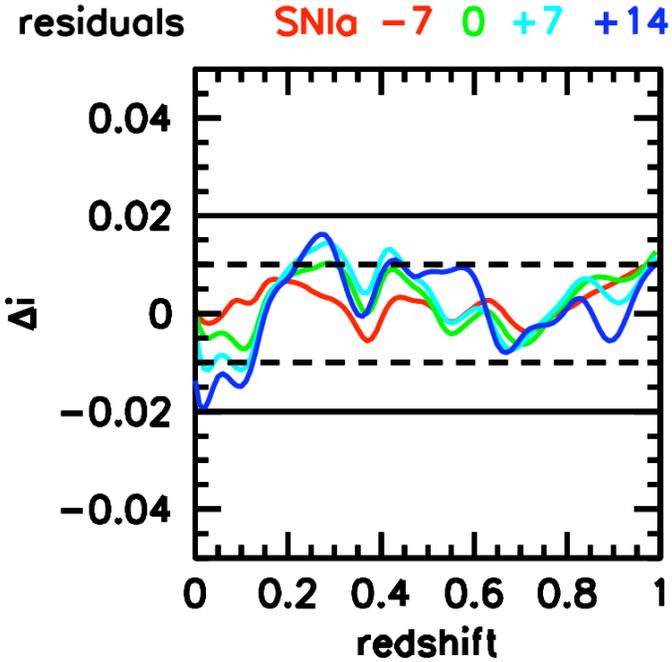
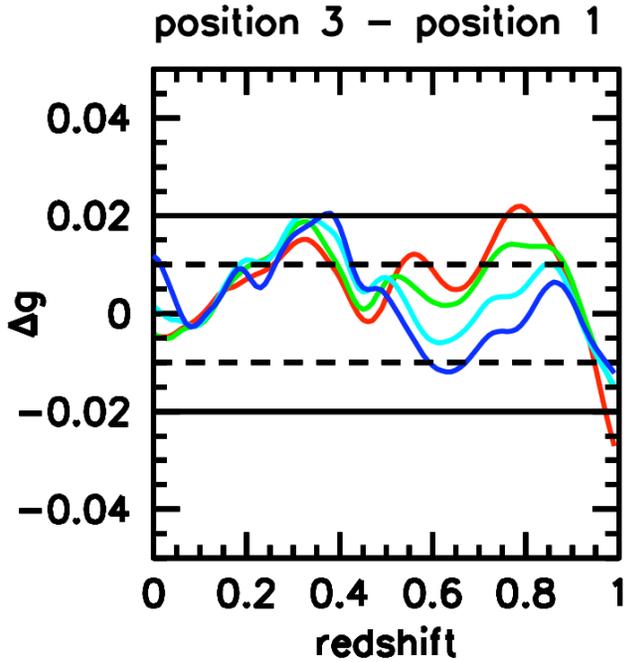
- **S-16** The magnitudes of an object may be calculated to within 2% by convolving the spectrum of the object with the system response curves. This requirement assumes that the spectra are spectrophotometrically calibrated and that the system response curves are absolute.
 - *This is the total photometric calibration requirement*
- **S-17** The magnitudes vary only by $-2.5 \log f_2/f_1$, independent of position in the final map to within 2% (1% enhanced goal), where f_2/f_1 is the ratio of photon fluxes. This is to be true in g, r, i, z individually.
 - *This is basically the relative photometric calibration requirement*
 - *We'll focus on this*
- **S-18** The magnitudes have an absolute zero point that is well-defined and known to 0.5%. The magnitudes will be on the natural instrument system.
 - *This is basically the absolute photometric calibration requirement*



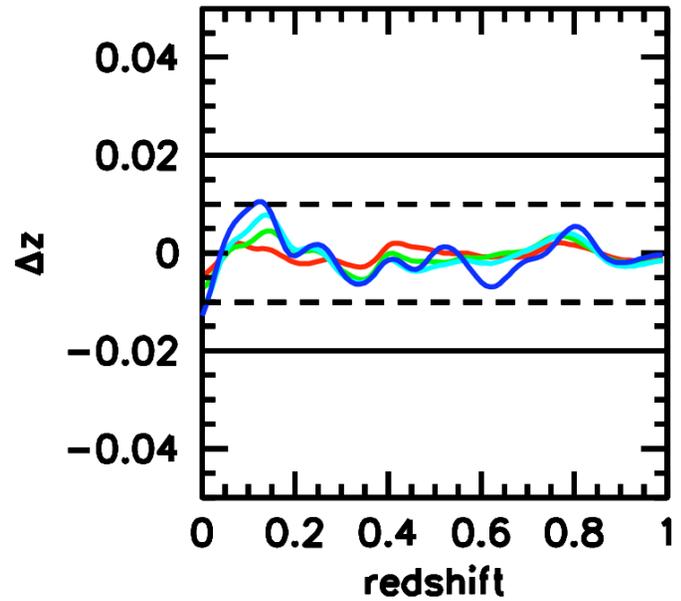
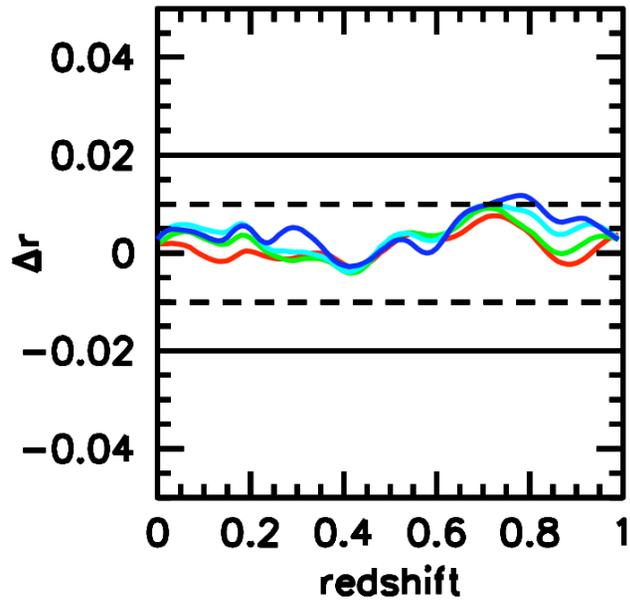
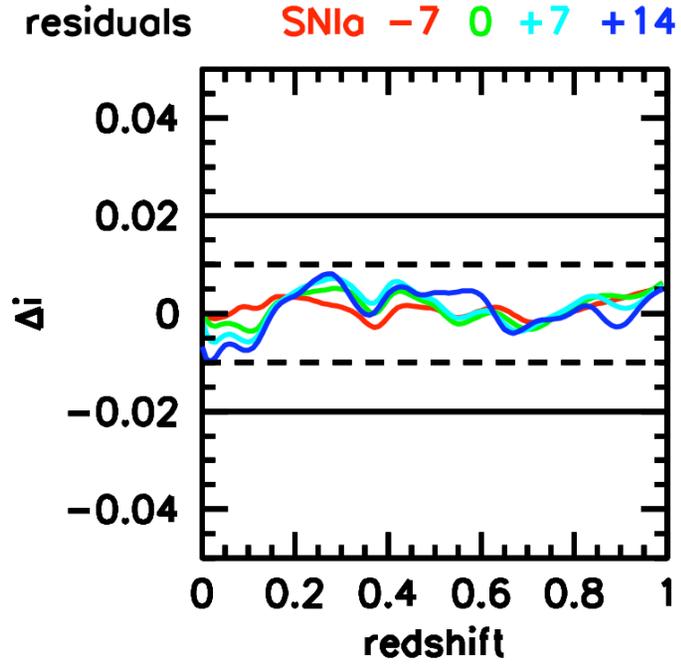
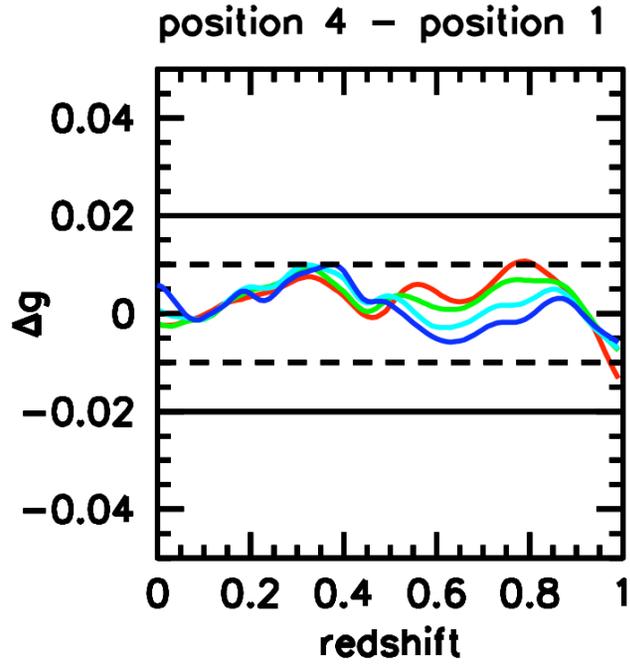
Proposed Relative Photometric Calibration Science Requirements

- **S-19 Uncorrected nonlinearities** due to imperfect shutter timing and nonlinear CCD/amplifier gain shall be less than 0.3%, measured as the peak error between shortest and longest exposure times, and between the faintest and brightest unsaturated stars.
- **S-20** The **aperture correction** shall have an internal rms error no bigger than 0.6% for any CCD and seeing between 0.8" and 1.5".
- **S-21** The rms photometric errors due to **imperfect flatfielding** (including errors in removing the ghost image of the night sky and removing other stray light sources) will be no worse than 0.84%.
- **S-22** The rms photometric variations due to spatial changes in the **shape of the system optical transmission** (telescope, corrector lenses and coatings, and filters) will be no worse than 0.84%.
- **S-23** The rms photometric variations due to spatial changes in the **shape of the CCD QE vs. wavelength** curve will be no worse than 0.84%.
- **S-24** The rms photometric errors due to imperfect removal, using the global relative photometric calibration solution, of temporal and spatial changes in the **atmospheric transparency and extinction**, will be no worse than 0.84%.
- **S-25** The rms photometric errors due to imperfect corrections for **astrometric and other distortions** on the focal plane (including those due to the optical design and to the CCD "glowing edges") will be no worse than 0.84%.

- **Kept 1st two requirements at 0.3% and 0.6%**
- **Leaves remaining 1.88% for last 5 terms, divide by sqrt(5) to get 0.84% per requirement**



SNe Ia
 $\pm 10\%$
gradient
filters



SNe Ia
 $\pm 5\%$
gradient
filters